PHOTOGRAPH THIS SHEET

A950384

DTIC ACCESSION NUMBER

LEVEL

Watertown Arsenal Labs. MA

INVENTORY

Rept. No. WAL - 121/2

DOCUMENT IDENTIFICATION

May 40

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR		
NTIS	GRA&I	☒
DTIC	TAB	☐
UNANNOUNCED		☐
JUSTIFICATION		
(May 1940)		
BY		
DISTRIBUTION / Per Ltr. on file		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A		

Released

DISTRIBUTION STAMP

DTIC
ELECTE
S MAY 20 1981 D
D

DATE ACCESSIONED

UNANNOUNCED

81 5 15 214

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

A950384

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

REPORT NO. 121/2

INSPECTION MANUAL FOR METALS

MAY 1940

WATERTOWN ARSENAL
WATERTOWN, MASS.

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

TABLE OF CONTENTS

Section VII - Nondestructive Tests

INSPECTION MANUAL FOR METALS

SECTION I

General

1. Purpose. This manual is for the use and instruction of Ordnance inspectors engaged in the inspection of metals. It is intended to provide sufficient detailed explanations and technical descriptions for the proper and efficient application of any specification for the procurement of metallic materials.

2. Scope. The field of the manual covers all types of metallic material from raw material to finished structures or structural elements, excluding only welded structures or elements for which special manuals have been issued. This manual must not be considered as authorizing any action on the part of the inspector not warranted by the contract, purchase order, drawings, or detail specifications. Individual specifications and the contract or purchase order of which it is a part will, in each instance, form the sole basis for acceptance or rejection.

3. Necessary supplementary information or publications. In addition to the General Inspection Manual, the inspector should have and be familiar with:

(a) The contract for each order which is to be inspected.

(b) Complete sets of drawings for material being manufactured for contract (where drawings are required).

(c) The pertinent issue of applicable specifications.

(d) Copies of all correspondence relating to the order.

(e) Copies of forms required for inspection reports.

(f) Published standards as required (as under section on Macro-examination, Radiography, etc.).

4. Contract. The term "contract", as used hereafter in this manual, shall be construed to include contract, drawings, and applicable specifications.

5. Precedence. Should any conflicts exist between the requirements of the contract, the drawings, the detail specification, or the General Specification for Metals, QQ-M-151, the requirements shall prevail in the order named.

6. Decisions in Doubtful Cases. In borderline cases, where the inspector is unable to decide whether or not the particular material is acceptable, he must refer the case, together with all records and tests and his own recommendations, to the contracting officer for decision. It is proper and desirable to include the written opinion of the contractor.

7. Concessions. The inspector can permit no deviation from the requirements of the contract. Concessions can be made only by the contracting officer.

8. Types of Tests. The required tests are specified by the contract. It is generally the intent of specifications that the number of test

specimens and their locations shall be shown on the drawings. In general, the following tests may be required, and detailed instructions in regard to each are given in the respective sections:

Section IV	Chemical Analysis
Section V	Macro-examination
Section VI	Physical Tests
Section VII	Nondestructive Tests
	(1) Visual (2) Radiographic Examination
Section VIII	Microscopic Examination
Section IX	Corrosion Tests

SECTION II

Equipment

9. Inspection Equipment. Gages, measuring devices, and other equipment required by the inspector to determine compliance with the requirements of the contract are furnished by the Government or by the contractor, as determined by the terms of the contract. In general, the Government will furnish all gages and fixtures shown on the pertinent List of Gage Drawings. The contractor will in general furnish all other equipment. In some cases, special equipment is furnished by the Government. Before inspection is started, the inspector should study carefully each drawing and specification connected with the contract and should make a complete list of all equipment needed for the inspection. It is highly important that inspection equipment be available for use prior to the time that the material is expected to be ready for inspection so as to avoid delay in manufacture.

10. Contractor's Equipment. The inspector should assure himself of the adequacy and condition of any equipment furnished by the contractor for the inspector's use. Gage laboratories are maintained by the Ordnance Department where instruments may be inspected and calibrated. The contractor's testing equipment may be calibrated against Government equipment under conditions covered in the pertinent General Specification under the heading Manufacturing Gages.

SECTION III

Inspection Procedure

11. Drawings furnished by contractor. The contractor furnishes any working drawings he may need and it is his responsibility that they satisfy the requirements of the drawings furnished by the contracting officer. However, the inspector should check the drawings carefully, keeping in mind the extra metal required for tests, machining, or further processing. The early discovery of errors or deficiencies in the contractor's working drawings will help to avoid difficulties during manufacture.

12. Promptness. Where process inspections are required, the inspector or his assistant must be available with the proper equipment in order to avoid delaying the contractor's operations. Promptness in every detail of inspection, including final decision, is the right of the contractor and, also, is of benefit to the Government in that it greatly aids in expediting delivery.

13. Ladle Analysis. Samples for ladle analysis must be identified by the inspector.

14. Ingot-discard. The inspector must check the amount of discard from each end of ingot, remembering that discard is expressed as percentage of total ingot weight. In determining total ingot weight, the hot top is not considered a part of the ingot. Discards should be weighed occasionally and a check must always be made when any doubt exists as to the amount of discard taken. If the contractor should elect to have test metal taken out of any discard, the inspector should verify the fact that the finished forging will contain none of the prescribed discard.

15. Forgings. Steps necessary in inspection of forgings or forging operations are given by individual specifications or by the Gun Forging Manual - these should be rigidly adhered to. In general, observation and record should be made of the type of equipment used (press, hammer, etc.), amount of work or reduction of area, temperature of working and method of cooling after forging. Details of these and other significant points are definitely laid down by individual specifications.

16. Castings. Responsibility for the production of satisfactory castings rests wholly with the contractor. The inspector should make sure that individual castings, all test coupons and test blocks are properly identified by heat number or a distinct identifying mark.

17. Identification and Marking. The inspector's stamp should be at all times either in his personal possession or securely safeguarded. All material must be identified by marks or stamps placed in accordance with the provisions of detail specifications which must be strictly complied with. The inspector's identification marks are his guarantee that the piece is in each case the same as the one inspected after an earlier operation. The transfer of identification marks and their attestation by the inspector before obliteration is required and should be rigidly enforced. Prompt attestation of each transfer materially assists the contractor.

18. Identification of Test Metal. It is imperative that the inspector know positively that each test specimen was taken from the material it is intended to represent, had the location shown by the identification marks, and had no treatment of any kind other than that given the material it is intended to represent. The inspector should make preparation for insuring compliance with these requirements and should obtain the concurrence and co-operation of the contractor. Continual vigilance in every detail connected with test specimens is essential. Discs and

test metal cut from material under inspection are bright on the machined surfaces. If such test metal is subsequently heat treated, the surfaces will no longer be bright unless remachined after treatment. If remachined, this fact will be shown by the color of the surface of the indentation made by the inspector's stamp. In the case of forgings, the use of 12 o'clock and 3 o'clock lines are highly important in order to orient the test metal.

19. Test Specimens

(a) In fixing the location of test specimens, due regard must be given to leaving adequate metal for subsequent tests or finishing operations such as machining. In such cases, it may be necessary to depart somewhat from the specified locations of test metal, but any departure from the requirements must first be approved by the contracting officer. Contractors generally allow ample metal for tests, for their own information as well as for official tests; this practice should be encouraged.

(b) When the contract permits or requires tests to be made at the manufacturer's plant, every such test must be carried out by the contractor and witnessed by the inspector.

(c) When the contract requires tests to be made at some other establishment, such as a Government Arsenal, the inspector should fix the location of the test metal, measure distance between locations when necessary, attest the correctness of the identification marks and the location of 12 o'clock and 3 o'clock lines on discs by his stamp, verify shipment, and record the date and time of shipment.

(d) In case of material requiring discs for macro-etching, the same disc may be used for physical testing, in which case, the macro-etching must be made before the physical test specimens are prepared from the disc.

20. Surface Finish. The quality of finish required for any part is noted on the detail drawing There are at present no standards covering the various degrees of surface finish. It is necessary, therefore, for the inspector to consider the service use of the part in question in making his decision as to whether the degree of finish is that desired

21. Heat Treatment Heat treatments include all thermal operations (in any combinations or cycles of treatments) through which metals in the solid state are carried for purposes of improving their stability or their physical properties They may be of various kinds according to the purpose intended.

22. Heat Treatment Terms Unless otherwise specified in the contract, terms used shall be construed as defined in QQ M 151. Where there is no conflict with the above terms, the definitions given in the current issue of the Metals Handbook (A.S.M.) are adopted for this manual, except that the Ordnance Department recognizes stress relief anneal and quench hardening as defined below Some of the more frequently encountered terms are

(a) CRITICAL TEMPERATURE RANGE. At certain temperatures the properties of iron base alloys change very markedly due to internal transformation. These temperatures are referred to as critical temperatures, or critical points. Certain alloys may have several critical points, and the temperature range within which they occur is referred to as the critical temperature range The heat treatment of iron base alloys is governed by this critical temperature range.

(b) ANNEALING. A heating and cooling operation implying usually relatively slow cooling.

Note: Annealing is a comprehensive term. The purpose of such a treatment may be:

To remove stresses.

To induce softness.

To alter ductility, toughness, or other physical properties.

To refine the crystalline structure.

To produce a definite microstructure.

In annealing, the temperature of the operation and the rate of cooling depend upon the material being heat treated and the purpose of the treatment. Certain specific heat treatments coming under the comprehensive term "annealing" are:

(1) Full Annealing. Heating iron-base alloys above the critical temperature range, holding above that range for a proper period of time, followed by slow cooling to below that range.

Note: The annealing temperature is generally about 100°F. above the upper limit of the critical temperature range, and the time of holding is usually not less than 1 hour for each inch of section of the heaviest objects being treated (see tool section in Metals Handbook for tool steel practice). The objects being treated are ordinarily allowed to cool slowly in the furnace. They may, however, be removed from the furnace and cooled in some medium which will prolong the time of cooling as compared to unrestricted cooling in the air.

(2) Process Annealing. Heating iron-base alloys to a temperature below or close to the lower limit of the critical temperature range followed by cooling as desired.

Note: This heat treatment is commonly applied in the sheet and wire industries, and the temperatures generally used are from 1020-1200°F.

(3) Normalizing. Heating iron-base alloys to approximately 100°F above the critical temperature range followed by cooling to below that range in still air at ordinary temperature.

(4) Spheroidizing. Any process of heating and cooling steel that produces a rounded or globular form of carbide.

Note: The spheroidizing methods generally used are:

(a) Prolonged heating at a temperature just below the lower critical temperature, usually followed by relatively slow cooling.

(b) In the case of small objects of high carbon steels, the spheroidizing result is achieved more rapidly by prolonged heating to temperatures alternately within and slightly below the critical temperature range.

(c) Tool steel is generally spheroidized by heating to a temperature of 1380-1480°F for carbon steels and higher for many alloy tool steels, holding at heat from 1 to 4 hours and cooling slowly in the furnace.

(5) Tempering. (Also termed "Drawing".) Reheating hardened steel to some temperature below the lower critical temperature, followed by any desired rate of cooling.

Note: Although the terms "tempering" and "drawing" are practically synonymous as used in commercial practice, the term "tempering" is preferred.

(6) Stress Relief Anneal. Heating at a uniform rate to a temperature that will not impair physical properties of the metal by an undesirable amount, holding at temperature for a sufficient length of time to permit readjustment of stresses, and cooling at a uniform rate and slowly enough to prevent distortion.

(c) QUENCHING. Rapid cooling by immersion in liquids or gases or by contact with metal.

Note: Common quenching media are water, oil, brine, air, molten metals and salts.

(d) QUENCH HARDENING. (For iron-base alloys.) Heating and quenching certain iron-base alloys from a temperature either within or above the critical temperature range for the purpose of producing hardness superior to that obtained when the alloy is not quenched.

Note: For some detailed practices see Ordnance Document No. 2050, Part III, and section on heat treatment, current edition of Metals Handbook (A.S.M.).

(e) DRAWING. (Or tempering.) See "Tempering" above.

(f) AGING. Aging may be defined as the spontaneous change in the physical properties of a metal which occurs at a relatively low temperature after a final heat treatment or cold-working operation. The fundamental reaction involved is generally one of precipitation, sometimes submicroscopic. The method employed to bring about aging consists of exposure to a favorable temperature subsequent to, (a) relative rapid cooling from some elevated temperature (quench aging), or (b) a limited degree of cold-work (strain aging).

SECTION IV

Sampling and Chemical Analysis

23. General. Instructions or comments on raw materials (that is, ores, ferro-alloys, pig iron, ingot copper, pig tin or pig lead) will not be included as it is unlikely that inspectors in field service will find any occasion to sample or analyze them. Inspectors in manufacturing arsenals will find necessary information on these materials in specifications, available technical reference books or technical consultants who will give instructions regarding sampling, etc. In many instances the necessity for performing a chemical test must be determined by the judgment of the inspector.

24. Steel.

(a) PRINCIPLES TO BE OBSERVED IN SAMPLING.

(1) Different parts of a piece of steel vary in composition. The greatest variation usually occurs between the center and the outside of the piece.

(2) When a sufficient number of check analyses have been made on samples properly taken to represent the different portions of a melt, their average compares favorably with the ladle analysis which is the analysis of a small test ingot taken during the pouring of the melt.

(3) From this it is evident:

a. That the ladle analysis is more representative of the composition of a melt than any single analysis of the finished material.

b. That drillings for check analysis, to be representative, should be taken at a point intermediate between the outside and the center of the cross-section of the material.

c. That a sufficient number of pieces should be analyzed to constitute an average that will fairly represent the melt.

(b) PREPARATION OF SAMPLES.

(1) Each melt in a lot shall be considered separately, and pieces for sampling shall be taken to represent the melt as fairly as possible.

(2) Samples must be drillings or chips cut by some machine tool without the application of water, oil, or other lubricant, and shall be free from scale, grease, dirt, or other foreign substances. If samples are taken by drilling, a drill not less than 1/2 inch nor more than 3/4 inch in diameter shall be used.

(3) Samples must be uniform, well mixed, as fine as possible, and free from dust which causes low carbon values. Chips too coarse to pass a 20-mesh sieve are not recommended, nor long curly drillings which will not pack closely in the carbon run.

(4) In referring samples to the manufacturer or other analyst for check analyses, pieces of the full-size section, when possible, should be submitted rather than cuttings, unless the latter are especially requested.

(5) Chemical analysis of material that has been subjected to certain operations does not give results which properly represent its original composition. Therefore, samples should be taken

from the material in the condition in which it is received from the manufacturer.

(c) LOCATION OF SAMPLES.

(1) When the material is subject to tension test requirements, samples for check analysis shall be taken from the tension test specimens, or as prescribed in Paragraph 24(c)2.

(2) When the material is not subject to physical test requirements:

a. For large sections, including blooms, billets, slabs, rounds, squares, shapes, etc., samples shall be taken at any point midway between the outside and the center of the piece by drilling parallel to the axis. In cases where this method is not practicable, the piece may be drilled on the side, but drillings shall not be taken until they represent the portion midway between the outside and the center.

b. For bored forgings samples shall be taken midway between the inner and outer surfaces of the wall.

c. For thin material or material of small cross-section, such as plates, shapes, bars, etc., if Method a is not applicable, the samples shall be taken entirely through the material at a point midway between the outside and the center, or by machining the entire cross-section.

d. For sheets, the specimen for sampling shall be cut about 2 inches wide, cleaned by pickling or grinding, and then folded once or more by bringing the ends together and closing the bend. The sample for analysis shall be taken in the middle of this length, preferably by milling the inside sheared edges or by drilling entirely through from the flat surface.

For sheets rolled from slabs or bars longitudinally, the specimen for sampling shall be cut across the full width of the sheet as rolled. For sheets of light gage, more than one specimen may be taken and stacked together before folding.

For sheets rolled from slabs or bars transversely, the specimen for sampling, about 18 inches long, shall be cut from the side of the sheet and halfway between the middle and end as rolled. For sheets of No. 20 gage or lighter, the specimen shall be the full length of the sheet as rolled.

For sheets not of the full size rolled, the sample for analysis shall be taken by milling or drilling the sheet in a sufficient number of places so that the sample is representative of the entire sheet. The sampling may be facilitated by folding the sheet both ways.

25. Brass or Bronze. For castings, the sample may be taken from a tensile test specimen or from a representative casting selected by the inspector from each melt. Drillings or millings shall be taken from sound metal below the surface. For rolled or drawn bars, sheets or strips, the number of pieces to be sampled is given in specifications; in general, one piece from each heat is sufficient. Millings should be taken from full cross-section.

26. Aluminum or Aluminum Alloys. The tendency to segregation is greater as silicon or nickel content increases. Haphazard sampling, such as chipping off a corner here and there, or sawing through and through, drilling with various size drills at irregular locations is to be avoided as nonconducive to uniformity of sample. The number of pieces to be taken as a sample and the location and method of making chips for analysis vary, and

the individual specification in use should be consulted for instruction on this point.

27. Babbitt or Antifriction Metal. Instruction as to number of pieces to be taken as a sample and the location and method of taking chips for analysis is given in individual specifications and these should be consulted for details.

28. Methods of Analysis. Where methods of analysis are not prescribed, those published by the American Society for Testing Materials as "A.S.T.M. Methods of Chemical Analysis of Metals", of latest issue, should be used. Quantitative analysis by means of spectrograph should not be permitted except by special permission of the contracting officer. Some liberty in choice of methods may be granted by the inspector, provided he is satisfied that the accuracy of the methods used is proven by comparison with standard samples prepared by the National Bureau of Standards.

SECTION V

Macro-examination

29. General. This section is intended to provide detailed explanations and technical descriptions necessary to properly prepare and macro-etch test metal submitted for macro-examination. The interpretation of the structures disclosed by macro-etching are illustrated and described in the current Macrographic Standards Description of tests for season cracking is also included in this section

30. Definitions.

MACROSTRUCTURE - The structure and internal conditions of metal as revealed on a ground or polished (and sometimes etched) sample by either the naked eye or under low magnifications (up to 10 diameters).

MACRO-ETCHING (deep acid etching) - Treating a ground or polished metal surface with an etchant designed to develop details of macrostructure.

MACRO-EXAMINATION - The study of macrostructures to determine conformity with standards or for other purposes.

BAUMANN PRINTING A process of obtaining a special contact print from a steel or iron surface for the purpose of indicating sulphur- and phosphorus rich areas.

SEASON CRACKING - (See Paragraph 39).

31. <u>Application</u>. Macro-examination can be applied to many engineering metals, such as steels of every type, stainless irons, monel metal, bronze, etc., in any physical condition, such as forged, cast, rolled, or in any condition of heat treatment. Macrographic examinations are always made on the surfaces of the discs next to the body of the metal.

32. <u>Location of Test Metal</u>. Macrographic examinations are preferably made on test metal located as near to the finished product as is consistent with production requirements. In many cases this test metal will serve for macro-examination, micro-examination and physical tests.

(a) In the case of gun forgings, blueprints normally indicate the location of test metal. The manufacturer generally allows sufficient metal at each test location for three or more submissions.

(b) Breech block or breech ring forgings, if bought in multiple lengths, are represented by transverse discs taken from ends representing top and bottom portions of the ingot. Maximum length of bars is usually stated in the contract. For each disc removed from the forging, it is necessary to know the distance in inches from the breech or muzzle (top or bottom) end with reference to the shipping length. When such information is submitted, consideration can be given to any purely local conditions found on macro-examination. In many cases such defects will be removed before shipping length is reached, thereby leaving fully acceptable material.

(c) Rolled or forged products such as bar stock, tool steels, shapes, plates, etc., are sampled as required by contracts.

33. <u>Proper Identification of Test Metal</u>. Discs from gun forgings should be marked in accordance with the current issue of Specification No. 57 103. The inspector should identify test metal

from forged or rolled materials as to location so that additional test metal from the same or other locations may be supplied if required.

34. Preparation of the Surface. The necessary surface condition of test metal as prepared for macro-etching (or Baumann printing) is readily obtainable; rough saw marks or rough lathe marks are removed by grinding wet with an abrasive wheel. Care should be taken to avoid burning (overheating during grinding). As accepted for macro-etching, the disc should contain no scratches deep enough to be felt when the fingernail is drawn over the ground surface.

35. Baumann Prints. Baumann prints*, when required, are taken on the ground surface of the test metal prior to macro-etching

36. Macro-etching Procedure. Test metal to be macro-etched is placed in a pyrex beaker, large porcelain evaporating dish, or a rubber-lined steel tank. Sufficient Macro-etching Acid** is added to cover the piece so that evaporation

---

* See Appendix B

** The suggested Macro-etching Acid mixture contains:

12 parts by volume concentrated Sulphuric Acid (H_2SO_4) Sp. Gr. 1.83

38 parts by volume concentrated Hydrochloric Acid (HCl) Sp. Gr. 1.18

50 parts by volume Water (H_2O)

See also "Macro-etching", Metals Handbook.

losses will not expose the steel before the process is completed. The bath is heated rapidly to 70°C (160°F) and maintained between that temperature and 85°C (185°F) for a predetermined period of time. Any quality or strength of acid may be used for the mixture by making the proper allowances to obtain the actual acid content of the above-noted mixture. Where the amount of etching is large, the above-mentioned mixture may be economically purchased in carboy lots, since no time or apparatus is necessary for dilution and mixing of the individual acids in large quantities The etching time is not critical but will vary according to the composition of the steel, the fineness of the structure and, particularly, the amount of high temperature heat treatment the metal has had. The usual etching time for steel is from 10 to 40 minutes above 70°C (160°F). Light or short-time etching to develop flakes or flakelike areas, cracks or cracklike areas, is sometimes used. To stop the etching action, the beaker or dish and its contents are placed directly under a cold water tap and the water allowed to run into and overflow from the dish for 3 or 4 minutes, or until the bath is entirely acid-free. For large dishes or tanks, a rapid-acting syphon and a supply of incoming tap water to keep the pieces covered at all times is a satisfactory means of changing the acid. The etched discs, still covered with water, have on them a finely divided carbon sludge which must be scrubbed off By scrubbing briskly with a short, fairly stiff fibre brush while the piece is under the tap or in a shallow tray, all traces of carbon sludge can be loosened and removed. The etched disc, until now water covered, is transferred quickly to a table or convenient place for rapid drying. Most of the surface water is removed by two or three applications of dry paper towels in rapid succession, and then the disc is placed under a clean, hot, compressed air blast (air temperature 140°C) to finish drying. Sometimes the paper towel operation is omitted. Any other source of hot, dry, clean air will also be satisfactory.

37. Interpretation of Results and Correlation with Other Tests. This phase is best shown by a combined description and illustration of typical macrostructures. In this manner, by referring to the photomacrograph or the text, the terminology or the structures disclosed are readily compared. Current Macrographic Standards will cover this subject. A summary here will allow those employing the macro-etching test to know that properly etched test metal is expected to indicate:
(a) porosity, slag, or nonmetallic segregates;
(b) the presence of flakes, cracks, laps or seams;
(c) uniformity or nonuniformity of the structure.
A study of the macrostructure, together with a consideration of the other tests made, will indicate the usefulness of the material. The location of nonuniformities observed should be considered with regard to the final product when recommendations are made.

38. Report of Macrographic Examination. A short, concise macrographic report, on a suitable form, containing all necessary information, results of macro-etching test, and recommendations regarding the metal, should be forwarded to the contracting officer. A typical macrographic report, showing a form that has been considered satisfactory, is appended.

39. Strain Test for Season Cracking. Articles of many types of brasses and bronzes, such as pipes, tubes, sheet, strip, cartridge cases, or other forms or parts, are tested for the existence of harmful internal strains. If these strains are present, cracks develop (season cracks), particularly after storage, especially under corrosive conditions. To make the test, the specimens (the number and size of which are defined in the particular specification) are first cleaned and then immersed in a 40 per cent (by volume) solution of nitric acid for 30 seconds, washed in running water and then dipped, while wet, in the specified mercurous

nitrate solution for the required length of time. After removal and washing with water, the surfaces are examined for cracks, the existence of which is cause for rejection. The immersion of the specimen in the required solution produces a deposit of mercury on the surface. In critical work, when so instructed, the mercury is removed and cracks are searched for at a magnification of X10. If no cracks are developed within the specified time, experience indicates that no difficulty will be encountered under storage conditions. Illustrations of season cracks are shown in Section VIII, Plate VII.

APPENDIX "A"

Typical Macrographic Report

Report No. 312/1072
Macrographic Test

Date: July 19, 1939

Purchase Order 4637, Items A, B, & D

Heat: 69709

Manufactured By: Eastern Steel, Inc.

Material: WD-2340

Dimensions:

Item	Dia.	Length
A	3"	30"
B	3-1/4"	40"
D	5-1/2"	22"

Test Metal Location: Both ends of each item.

Form: Forgings - rough machined.

Condition: Forged, annealed, quenched and drawn.

External Inspection - not made.

Additional Data: Items A & B are for Elevating Mechanisms of 3" Gun Mount.
Item D is for gear shaft - 8" R.R. Mount.

Characteristics:

Item A - WD-2340 - 3" dia.

Discs stamped 1 & 2 - The disc shows a well-worked, quite uniform structure outside of the 1.5" diameter. Within this diameter, a few small scattered segregates are present. Macrostructure satisfactory.

Characteristics: (Cont'd)

Item B - WD-2340 - 3-1/4" dia.

Disc stamped 1 - This disc has several quite deep surface laps at the periphery. They extend to the 2.75" diameter. Metal adjacent to these defects is decarburized. The metal in the remaining part of the disc shows a fine uniform structure.

Disc stamped 2 - This disc shows no surface defects and the structure is uniform throughout. (Dia. of finish machined part is 2.975").

Macrostructure - End 1 - unsatisfactory
End 2 - satisfactory

Item D - WD-2340 - 5-1/2" dia.

Discs stamped 1 & 2 - The discs show a well-worked, well-broken, dendritic structure from the outside to the 3" diameter. From this diameter to the 1" diameter the metal shows a mixed structure with fine, well-scattered nonmetallics. Prominent coarse segregates associated with the ingot pipe are found within the 1" diameter.

(O.D. of finished part 5.325" - I.D. 1.25")

Macrostructure - satisfactory outside of the 1" diameter.

Recommendations:

Accept - Item A.

Reject - Item B - Take maximum possible discard from end #1 and resubmit disc for macroexamination.

Accept - Item D - Metal within the 1" diameter must be removed during manufacture.

Metallurgist

APPENDIX "B"

Baumann Print Procedure

The disc to be printed is washed carefully with a gasoline-soaked piece of absorbent cotton. This washing, to remove all dirt, oil and grease, must include the outside (and bore) surfaces as well as the transverse ground face. The piece is wiped dry with another ball of cotton and is now ready for taking the print.

Any ordinary photographic paper with matte or semi-matte surface is satisfactory. It is cut large enough to cover the entire cross-section and leave about 1/2" surplus beyond each edge for manipulation. On the back (nonemulsion side) of the paper are written complete identifying marks to show forging number, date, and o'clock position for later orientation of the print.

A 5 per cent solution of H_2SO_4 (sulphuric acid) in water is poured into a tray and the paper placed in it to soak for one (1) minute The paper is removed and surface liquid allowed to drain from it by holding the paper vertically by one corner for one (1) minute. The soaked paper (the emulsion now contains some H_2SO_4 - sulphuric acid) is then carefully placed emulsion side in contact with the disc, and all air and gas rolled from under the paper with a light rubber roller. At the end of one (1) minute, the paper is removed. It will have a brown-yellow pattern showing the sulphur and phosphorus distribution.

The print is rinsed in water, "fixed" in a half-strength photographic fixing bath (Hypo) for 1/2 hour, then washed and dried as an ordinary photographic print. The method is simple, quickly accomplished, and it is not necessary to use a darkroom. Direct sunlight or brightly illuminated rooms are avoided.

SECTION VI

Physical Tests

40. General. Physical tests for metals may be required by the terms of the contract, specification or drawing. The physical requirements for metals procured for Arsenal stock are given in the specification or contract. When metals are bought for a particular drawing application, the drawing indicates the physical requirements. If no physical requirements are indicated, physical tests are necessary only to determine that materials furnished are of the proper quality. In such cases, the extent of tests must often be regulated by the inspector's judgment.

41. Types of Tests. The physical tests normally required are:

(a) - Tension

(b) - Hardness

(c) - Impact

(d) - Bend

(e) - Special Tests

The tension test is required for practically all material purchased and is by far the most universally used test to determine the strength and ductility of material for use in a structure. The hardness test is required only for certain materials, such as tool steel, armor plate, etc., and for parts where it would be obviously impracticable to obtain a tension specimen. The impact test is normally required only for parts such as forged and centrifugally cast gun tubes and liners. The bend test is usually applied to material in the form of sheet and strip which is to be processed by cold forming or pressing operations, and in the testing of certain types of welded joints.

42. Tension Tests. Specifications usually require that acceptable material possess certain tensile properties. These may be referred to as proportional limit, elastic limit, yield point, yield strength, tensile or ultimate strength, percentage elongation, and percentage reduction of area. Of these, the tensile strength, elongation, and reduction of area present no difficulties since they are readily determined factors. The other terms are often misapplied and require more detailed explanation, since the practical determination of material property values in strict accordance with accepted definitions of these terms involves several factors which are not fully appreciated by many engineers and users of metallic material.

(a) PROPORTIONAL LIMIT. This term is defined as the greatest stress which a material is capable of developing without a deviation from the law of proportionality of stress to strain. The determination of accurate proportional limit values is dependent upon the accuracy and sensitivity of the equipment used and the condition of the material under test. Materials submitted for acceptance are seldom in a perfectly stabilized condition, and because of this, do not exhibit a perfect stress-strain relationship, thus eliminating any possibility for correct proportional limit determinations.

(b) ELASTIC LIMIT. This term is defined as the greatest stress which a material is capable of developing without permanent deformation remaining upon complete release of stress; also signifies a property value which is practically impossible to accurately determine.

Note: The use of the terms, "proportional limit" and "elastic limit", is not recommended unless the specific method for determining the value which the term is intended to indicate is clearly stated.

(c) YIELD POINT. This term is defined as the stress producing a marked increase in extension without increase in load, and is intended to apply to those materials which exhibit a sharp knee or drop in the stress-strain diagram. Except for steel castings and some of the wrought low carbon steels, very few materials exhibit this condition. The term has been used to mean anything from proportional limit to tensile strength and is specified on many of the less recent drawings and in certain specifications, although the material to which it is applied has no yield point characteristics. Values reported as "yield point" should be questioned, therefore, unless the definite sharp knee or drop characteristic can be shown to exist.

(d) YIELD STRENGTH. To eliminate the confusion resulting from the misapplication of the several terms referred to, the single term, "yield strength", has been adopted by the A.S.T.M. which has definite significance. This term is defined as the stress at which a material exhibits a specified limiting permanent set. Its use is applicable to all classes of materials. The several methods for the determination of "yield strength" values are described in detail in Specification QQ-M-151 and should be followed explicitly.

(e) TENSILE STRENGTH. This term is defined as the maximum stress which a material is capable of developing based on the original cross-sectional area of the specimen. Actually, the tensile strength value is not the maximum stress since this occurs at the break and is based on the reduced section. The significance of the term, "tensile strength", is that it represents the maximum resistance offered by the material to an applied load and, therefore, is a reliable indication of the so-called hardness of the material.

(f) ELONGATION AND REDUCTION OF AREA. The ductility of a material is indicated by the elongation and reduction of area percentages. The term, "elongation", represents the percentage increase in gage length, and the term, "reduction of area", the percentage change in sectional area produced during rupture.

43. Hardness Tests. Hardness tests are required for both ferrous and nonferrous materials, and particularly for extremely hard materials, such as tool steel, armor plate, etc., as well as for small parts where it would be obviously impracticable to obtain a tension specimen. The test is also used to check the results from heat treatment and as a means for insuring uniformity of material to be placed in quantity production. In the case of welds, the hardness test is used to determine variations throughout the welded joint. While there is no absolute relationship between hardness values obtained from the different types of test machines, tables of approximate conversions are available in the A.S.M. Metals Handbook.

44. Impact Tests. Impact tests are normally only required by specifications for forged and centrifugally cast gun tubes and liners and certain types of welds. The primary purpose of the impact test is to determine the characteristic behavior of a material when subjected to a suddenly applied load. There are two general types of impact test machines - the pendulum or single velocity machines, such as the Charpy or Izod, and the rotary machines, such as the Carpenter Torsion and Variable Velocity Impact machines. In the Charpy machine, the specimen may be broken either in

tension or transverse bending; in the Izod machine, as a cantilever beam; in the Carpenter machine, under torsion loading; and in the Variable Velocity Machine, the specimen may be tested in tension, transverse bending, or as a cantilever beam, and at any velocity up to 250 or more feet per second. The Carpenter Torsion and Variable Velocity Impact machines are of recent development. The Charpy and Izod machines are associated with the initial research on the subject of impact loading; therefore, impact tests referred to in specifications are usually designated as either Charpy or Izod tests.

45. Bend Tests. Bend tests are usually applied to sheet and strip material to determine their suitability for cold-forming operations, and to welded joints and certain of the castings as a test for ductility and soundness. Although specified in certain of the bar and plate specifications, the bend test is usually waived provided the tension test is applied. In the case of cast iron, acceptance is based primarily on the load-deflection values obtained from bend tests of cast bars. The bend test is utilized far more for special tests than it is for the determination of physical constants.

46. Selection of Test Specimens. The number and location of test specimens are usually given in the contract. When not prescribed, the number and location must be determined by the inspector. It is essential that test specimens be selected so as to give a reliable indication of the material as a whole.

(a) ROLLED OR FORGED BARS. In the case of rolled or forged bars up to 1-1/2" in diameter or thickness, the axis of the specimen should coincide with the central axis of the piece. For bars 1-1/2" to 4", the axis of the specimen should be one-fourth the diameter or thickness from the surface and parallel to the direction of rolling. In the case of pieces over 4" in diameter or thickness the test specimen should be transverse and located one-fourth the diameter or thickness from the surface, in the case of solid bars or forgings, and at the middle of the wall of bored or hollow forgings. The number of specimens selected depends largely upon the purpose for which the material is to be used. Ordinarily, in the case of material up to 1-1/2", one test from each lot or heat is sufficient. For bars 1-1/2" to 4" in section, one specimen from each bar is desirable. In the case of bars or forgings over 4" in section, at least two specimens 180° apart should be taken from the end nearest the top of the ingot as cast. In the case of forgings for important parts which are purchased subject to macro-etch examination, it is sometimes considered desirable to have specimens taken from each end to check the degree of uniformity throughout the forging.

(b) CASTINGS. Test specimens are usually machined from coupons attached to the casting or from separate blocks cast during the pouring of the heat. Unless specifically noted on the drawing, the location of attached coupons is determined by the contractor.* The form of test block for separately

* While no general rule can be laid down for the location and dimensions of attached coupons, it is desirable that they be large enough in cross-section to cast solidly and not be porous or dirty, and that they are located so as not to 'bleed' the casting and yet be fed so as to be sound. Due to variations in the different sections of most castings, and such factors as rate of feeding, position of risers or sinkheads, shrinkage, etc., the test specimen can merely be considered as a means for obtaining a general indication of the physical properties in those parts of the casting having similar section, which are fed and cooled in approximately the same manner as the test coupon.

cast specimens is designated in the General Specification for Metals, QQ-M-151.

47. Marking of Test Specimens. It is essential that the test specimens be so marked that the full history of any piece which they represent can be readily traced. Where more than one specimen is taken, the marking must be such that their location can be readily identified. In the case of purchased material, each specimen should be stamped with the purchase order number and such other identification symbols as may be considered necessary. In the case of forgings requiring two or more test specimens, the procedure outlined in the Gun Forging Specification No. 57-103 should be followed. When the test metal is an integral part of the material, marks to enable positive identification must be applied prior to removal of the test specimens and the procedure specified in Section 15, Specification QQ-M-151, strictly adhered to.

48. Test Specimens. The form and dimensions of the several types of test specimens are designated in the General Specification for Metals, QQ-M-151, and should be strictly adhered to. Test specimens should be cut from the piece by cold sawing or drilling and subsequently prepared by turning, milling or planing. Cutting to size and shape by burning should not be allowed, as this process may sufficiently alter the material structure to nullify the test results. Specimens from plate or sheet material should be reasonably flat and machined symmetrical about the central axis. Test specimens which are bent or otherwise deformed, except by removal of metal by machining, should be discarded, since any straightening by bending, hammering, or other means may seriously affect the elastic properties and reliability of the test results.

The most important part of a test specimen is the gage section, and the most consistent results will be obtained if this section has a smooth finish free from any circumferential marks or scratches and is slightly tapered toward the middle. The radius of the end fillet is not of any great importance, but it is absolutely essential that it join the gage section smoothly with no undercutting. Circumferential tool marks, particularly in high strength material, localize stress concentrations and may result in lowering the normal elongation percentage obtained from the test. The slight taper toward the middle of the gage section tends to force the break to occur at this point and thus give a more correct indication of the ductility of the material as a whole.

49. Testing Equipment

(a) TENSION

(1) The tension testing machine may be of any type, provided it is sensitive to slight variations of any recorded load and the actual load on the specimen can be accurately determined. In the types of machines in general use, the load on the specimen is applied by screws or by hydraulic pressure. In the screw power machines, the load is usually measured by a movable poise on a weigh beam, while in the hydraulic machines load measurements are obtained by an automatic indicating mechanism.

It is highly important that the testing machine be accurate. The General Specification for Metals, QQ-M-151, paragraph 22a, permits an error for indicated loads of not to exceed 1 per cent. The degree of accuracy can be determined properly only by the use of a proving ring or similar device which has been checked and approved by the National Bureau of Standards. Calibration by means of dead weights while permitted by QQ-M-151a is impractical in most cases, and the use of comparison specimens, part of which have been tested on another machine of certified accuracy is not permitted because of inherent material variations which may be greater than the permissible error specified.

Before permitting any Government tests to be made, the inspector should insure that the testing machine is in good condition and has recently been calibrated. The several manufacturers of testing machines and the National Bureau of Standards maintain a calibrating service which can be employed in cases where the contractor does not have such equipment available. The procedure to be followed should conform to that detailed in the American Society for Testing Materials, Standard E4 36, Standard Methods of Verification of Testing Machines.

(2) The extensometer is an instrument for measuring the strain or elongation produced in the tension test specimen by load applications up to or slightly beyond the yield strength of the material. The instrument must be of the type which automatically averages the strain on diametrically opposite sides of the specimen and must be sensitive to extensions of 0.0001 inch per inch. The following types of extensometers have been approved by the Department:

Southwark-Peters Averaging Extensometer
Averaging Dial Type Extensometer
H. F. Moore Extensometer
Olsen Adjustable Extensometer
Olsen Special Sub-size Extensometer
Ewing Extensometer

To be approved by the Department, extensometers should be as light as possible and designed so as to be rapidly attached to or detached from the test specimen without interfering with the application of the load. The instrument should, if possible, be self-contained. Since it is practically impossible to obtain perfect axial loading, the extensions on diametrically opposite sides of a specimen will not be exactly the same It is essential there fore, that the extensometer be of the type which records the average of these different amounts of strain. If the contractor desires to use an extensometer other than those listed, request accompanied by a complete description of the instrument, should be submitted through the in spector to the Contracting Officer for approval

The extensometer may be attached to the specimen by pressure on either pointed pins or knife edges These contacts should be kept sharp and clean at all times. Through constant use, knife edges become dull or chipped and, if found in this condition, the extensometer should be re turned to the manufacturer for repair and recalibration If the inspector has reason to doubt the accuracy of any extensometer, he should insist that it be checked, preferably by the manufacturer, since suitable calibrating instruments are not usually available in the ordinary commercial or plant laboratory

(b) HARDNESS The types of hardness tests normally required by specifications are the Brinell, Rockwell or Scleroscope. The Vickers hardness test is more applicable for research investigations, and is not in general use for inspection purposes Details of the use of these machines are covered in the General Specification for Metals QQ-M-151

To insure accuracy, hardness test machines should be frequently checked by testing on standard blocks especially prepared for this purpose. Hard ness testing machines as a general rule, maintain their accuracy over long periods of time.

(1) Brinell. In the case of the Brinell machine, the principal sources of error are

in the ball indenter and the diameter-measuring microscope. The ordinary steel ball used as in indenter becomes deformed when used on materials having a hardness of approximately 450 or more Brinell. The impression produced by a deformed ball will not be perfectly spherical and when this condition is observed, a new ball should be substituted. A simple check is to make an impression on a smooth ground surface of fairly soft and uniform material. If the surface of the indentation is smooth and uniformly round, the ball may be considered satisfactory. The accuracy of the microscope used for measuring the diameter of the impression is dependent upon the spacing of the lenses. Since the eyepiece lens is not permanently fixed, jarring of the instrument by dropping or other causes is likely to change the correct setting. It is essential, therefore, to frequently check the microscope on a standard scale which is normally supplied with the instrument.

(2) Rockwell. In the Rockwell machine, incorrect values are generally due to a broken diamond penetrator or dirt, which causes low readings, or to a flattened ball, which causes high readings. The inspector should make it a practice to have the machine frequently checked with standard blocks and any defects corrected.

(3) Scleroscope. In the case of the Scleroscope, the anvil occasionally becomes magnetized and when in this condition, the magnetic attraction to the piece being tested reduces the height of rebound and results in low readings. This condition should be frequently checked and, if found, should be corrected by demagnetizing the anvil.

(c) IMPACT. Impact tests are normally conducted on pendulum machines of either the Charpy or Izod types. The purpose of the test is to apply a sudden blow to a specimen sufficient to break it, and to measure the energy required for rupture. Since the energy value must be mathematically computed. ac curate calibration is possible only from careful computations involving the mechanical constants of the machine. Because of this condition, it has been the practice to check other machines used by comparing the results from specimens of a given material with those tested on the Charpy impact machine at the Watertown Arsenal.

50. <u>Testing Procedure</u>.

(a) TENSION. Before testing any specimen, the specified gage length should be laid out on the reduced section by light prick punch marks in order that the percentage elongation can be determined after rupture.

It is important that the percentage elongation be measured over the gage length specified for each given size of specimen. It has been found that when the gage length is equal to four times the section diameter, or more accurately $4.5\sqrt{\text{Area}}$, the resultant percentage elongation values obtained from different sizes of specimens of the same material are the same. In the case of plate of sheet material, it would be impractical to adopt a varying gage length proportionate to the cross-section. In these cases, therefore, the elongation requirements are based on a fixed gage length applied to all thicknesses. Where specifications permit either a 2" or 4" gage length, the former is preferred since it requires less material and allows for the use of standard commercial gages.

The specimen is then placed in the testing machine and the extensometer attached to the reduced section of the test specimen, the pointed or knife edge contacts being in line circumferentially with the prick punch marks. In all cases, the extensometer reading for zero or initial load must be accurately determined before proceeding with the test. Once the load has been applied, no adjustment of the initial setting of the extensometer should be made.

The rate of load application has a marked influence on the yield and to a limited extent on the tensile strength values obtained. It is highly important, therefore, that within the yield range the rate of stress application should not exceed 30,000 lbs/sq.in. per min. Above the yield range, the rate can be increased but should be such that the load is accurately indicated at all times. Test results obtained at rates of load application greater than specified should not be accepted.

When the yield zone has been reached, the extensometer should be detached from the specimen and loading continued until fracture takes place. The two halves of the test specimen are then removed from the machine, accurately fitted together, and the total elongation in gage length and diameter at the point of fracture measured.

The percentage elongation is obtained by dividing the difference between the final and original gage lengths by the original gage length and multiplying by one hundred.

The percentage reduction in area is obtained by dividing the difference between the original cross-sectional area of the gage section and the area at the point of rupture by the original cross-sectional area and multiplying by one hundred.

(b) HARDNESS. The correctness of hardness readings is largely dependent upon the preparation of the supporting and work surfaces of the piece tested. For Brinell and Rockwell tests, the surface should be well-cleaned by filing, grinding, machining or polishing with emery paper. Any surface imperfections or decarburization should be removed. Impressions should not be made so close to the edge that the material will bulge out at the side. For Brinell tests, the piece must be of sufficient thickness that no sign of the impression appears on the under surface. Specimens to be tested with the Scleroscope must be smoothly polished, set level, and the instrument held vertically. Thin specimens must be firmly supported to prevent springing. No two readings should be taken on the same spot since erratic results will be produced.

In conducting hardness tests required by a specification, it is important in the case of the Brinell test to report the load used, and in the Rockwell test, the scale designation.

In the Brinell test, it is customary to use a 3000 Kg load for ferrous materials and for nonferrous materials having a hardness of over 200 Brinell. For the softer nonferrous materials, such as brass or bronze, the 500 Kg load is used.

In the Rockwell test, the "C" scale, diamond penetrator and 150 Kg load, is used for materials of over 200 Brinell. The "B" scale, 1/16 ball and 100 Kg load, is used for materials of medium hardness, such as low and medium carbon steels in the annealed condition. For the softer materials, such as copper, brass, bronze, and other nonferrous alloys, other standard scale designations are available covering different combinations of load and penetrator.

Before using the Rockwell machine, its accuracy in the desired range should be checked by means of standard test blocks. The procedure of testing should be as prescribed in the pamphlet furnished with the machine or as detailed in A.S.T.M. Standards of current issue.

All machines for hardness testing should be protected against vibration as this condition will affect the correctness of the results.

(c) IMPACT. Before conducting an impact test, the machine should be checked for excessive friction in the bearings or drag on the recording devices. A properly adjusted pendulum type machine of 120 ft.lb. capacity should not lose more than 0.5 ft.lb. in one complete free swing of the pendulum. The friction of the recording devices should be the minimum that will prevent overcarrying of the indicator or dropping back with the pendulum.

The mechanism for releasing the pendulum from its initial position should operate freely and permit release of the pendulum in a free start without initial impulse, retardation or side vibration.

Tension impact specimens are screwed into the pendulum and have a tup or striking block screwed onto the other end. The tup should strike square against both horns; otherwise, the specimen will be bent and incorrect readings obtained.

Transverse notched specimens should be located preferably with a gage so that the blow is struck directly back of the notch.

The test report should state the type of specimen used, size of gage section or dimensions of notch and section at base of notch, striking velocity and energy required for rupture. If any specimen fails to break, the blow should not be repeated but the fact should be recorded, indicating whether the failure to break occurred through extreme ductility or lack of sufficient energy in the blow. Such results should not be used in determining average values.

(d) BEND. Bend tests are generally conducted on a universal tension-compression machine using fixtures furnished with the machine for this purpose The test specimen, usually a flat strip about 1" wide, 1/2" thick and 6" long, having the long edges slightly rounded, should be first bent through an angle of about 10 to 20 degrees at points approximately 2" from each end, or far enough from the final point of maximum bending so as not to affect it. With the specimen bent in this manner, compression loading is applied to the ends to produce free bending until the specimen closes in or failure of the outside fibers occurs. In the case of thin plate or sheet material where the radius of the bend is specified, the test can be readily made in a vise using a pin of the diameter required. In the tests of heavy plate and welded joints, a form of bend test referred to as the "nick-break" test is usually required. This test consists of cutting a groove or nick in the specimen and breaking by either slow bending with the notch on the outside of the bend, or a sudden blow. Acceptability is determined from the characteristic appearance of the fractured surface.

51. Special Tests. Tests are occasionally required of built-up subassemblies, such as outriggers, recoil slides, and other parts, such as piston rods, wire rope, springs, etc. The tests of built-up or partially completed structures are usually for the purpose of determining the effect of types of loading similar to those encountered in service. In the case of outriggers, the test consists of applying repeated cycles of loading at the outer end of the structure to simulate the shock load conditions encountered in service. Recoil slides are tested at maximum service loads to determine acceptability

of the welded trunnion joints. In the testing of wire rope, it is important that proper clamps and test fixtures be used so that no sharp bending or crimping of the wire occurs.

In tests of springs, the requirements for those of the coil type are specific, and the test results are dependent only on the dimensions and number of coils in the spring. In the testing of leaf springs, however, it has been found that the load required to produce a given deflection may vary as much as 10 per cent, depending on the condition of lubrication between the leaves. Thus, if the leaves are assembled dry, the load may be 10 per cent higher than when the friction surfaces are coated with a graphitic lubricant. Since the elastic modulus for steel is, for all practical purposes, a constant, it follows that, assuming the design calculations to be correct. leaf springs should be inspected simply for compliance with form and dimensional tolerances and lack of permanent set under maximum load conditions.

52. Fracture Surfaces of Test Specimens. The appearance of the fractured surfaces of broken test specimens is a valuable indication of material quality and applicability. Such examinations should be used in conjunction with the physical property values in judging the acceptability of material.

In general, the appearance of fractured surfaces of tension test specimens may be considered as of four distinct types, each of which may be further subdivided: cupped, laminated, irregular and woody.

(a) Cupped fractures are those in which one-half of the specimen shows a truncated cone and the other half a conical or cuplike depression surrounded by a ring or lip, and are indicative of homogeneous material, practically free from inclusions and segregations. The more homogeneous the steel, the deeper the cup obtained. Pitting at the base of the cup is evidence of local defects, the magnitude of which is in proportion to their number and size. Specimens which show cupped fracture are considered of the best quality material.

(b) Laminated fractures are those which have the appearance of the edges of thin plates laid one against the other, running in one direction across the surface of the fracture. Such fractures indicate the presence of metallic or nonmetallic segregation which has been compressed and elongated between laminations during processing. Specimens which break with laminated fractures often give excellent physical properties, but cannot be of the best quality because of the nature of the segregations.

(c) Irregular fractures are those in which the path of rupture appears to have followed no definite direction other than the line of least resistance, the contour being, as the name implies, irregular. Such fractures generally contain patches of laminations and are usually indicative of the presence of segregated areas, metallic and nonmetallic inclusions, and sometimes a flakelike condition. Specimens breaking with irregular fractures are associated with inferior quality material, and while the strength properties may be passable, the ductility and impact values are apt to be low and variable.

(d) Woody fractures are those having the appearance of old rotted wood, and are to some extent a combination of laminated and irregular conditions. Such fractures are indicative of a considerable amount of sulphide segregation, and metallic inclusions which have been partially drawn out during processing. Specimens having woody fractures are apt to show very irregular physical properties and particularly low impact strengths, and should indicate the necessity for further investigation of the material before final acceptance.

53. Interpretation and Use of Test Results. Material specifications are simply definitions of the properties of the materials which are desired. They represent the best effort to state in measurable terms those properties which are considered necessary for satisfactory use. They include certain requirements and methods of tests to determine compliance with these requirements and serve to provide a standard basis for inspection agreeable to both the supplier and the purchaser. One of the principal disadvantages of a material specification is the difficulty of adequately covering properties for all the contingencies of use, and it is therefore the duty of the inspector to carefully consider both service requirements and test results in making his decision as to the acceptability of material which may be deficient in certain of the properties specified but which might be perfectly satisfactory for the purpose intended.

When tension properties are specified, material which is below the specified requirements for yield strength and reduction of area should be definitely rejected. The yield strength value indicates the stress which can be applied without destroying the usefulness of the material. Safety factors are based on this value and the acceptance of material much under the limit specified may result in failure of the part in service. The ductility value is an indication of material quality and it is important that it be held as high as possible, particularly if the part is subject to dynamic loading.

The tensile strength value is not of as great importance as is generally assumed, and materials which meet the yield strength and ductility requirements but which are deficient in tensile strength should not be summarily rejected. The term, "tensile strength", is a heritage from the past when the methods of test were such that accurate yield values could not be readily determined. The maximum load being easily obtained, this value in terms of stress based on the original area of the specimen, was considered a reasonably indication of the probable actual yield strength of the material.

The real significance of the term, "tensile strength", is that in terms of load, and not stress, it represents the maximum resistance offered by the material to an applied load and is thus analogous to the Brinell hardness test. The relation between tensile and Brinell has been well established for the ferrous and many of the nonferrous materials, and the tensile strength should therefore be considered as an indication of the hardness of a material. There is no clearly defined relation between tensile strength and yield strength, as this varies with the material composition. Material deficient only in tensile strength, therefore, should not be summarily rejected if the hardness is sufficient for the purpose intended.

Hardness, although as a term extremely vague in meaning and often loosely applied, as a relative test has become invaluable towards facilitating a better control of material processing. The term by itself may have most any meaning from resistance to wear to a conception obtained from the sense of touch. Its use with respect to metallic materials is generally as a subsidiary to the tension test. Because of the established empirical relationship between hardness and tensile strength, hardness tests may be applied in lieu of tension tests in cases where it would not be convenient or practical to obtain tension test specimens. In such cases, if the composition of the material is known, a reasonable approximation of the physical properties can be readily determined.

Since the hardness impression involves only a small fraction of the material as a whole, acceptability should be based only upon the average of several readings. In judging the acceptability of a material on the basis of hardness tests, consideration should be given to the fact that in the Brinell test readings are generally taken to the nearest .05 mm., which means a possible variation of from 10 to 15 points in hardness number. While readings to .01 mm. can be made if the impression is on a specially prepared polished surface, this is not the general practice commercially. In the Rockwell test, differences of one point correspond to 10 to 15 points in Brinell number. Since there is also a permissible variation of plus or minus one point in the standard Rockwell test blocks, it should be quite evident that limits of less than 20 to 30 points Brinell or 2 to 3 points Rockwell are impractical and, if specified, should be questioned before final decision is made.

SECTION VII

Nondestructive Tests

54. General. Any test that may be applied to material and that does not render it unfit for service may be called a nondestructive test.* Examples of such tests are:

a. Visual inspection.

b. Various electrical and magnetic tests for soundness or for surface discontinuities.

c. Acid testing for surface discontinuities.

d. Proof testing where materials are stressed to a point below their elastic limit.

e. Radiographic inspection.

55. Surface Inspection includes all methods of surface examination with or without aids to vision. It is divided into three divisions for the purposes of this manual, viz:

Visual Inspection

Magnaflux Inspection

Acid Testing

a. Visual inspection** includes principally inspection for dimensions and straightness, for surface conditions, for laminations, and for cracks.

---

* References to the literature of nondestructive testing are given at the end of this section.

** See Reference 8.

(1) Inspection for dimensions and straightness requires measurements with the aid of instruments for dimensional characteristics and freedom from warping.

(2) Visual inspection for surface conditions involves such items as cleanness and regularity of surface, surface finish, scale, folds, cold shuts, surface checks, and cracks. Usually the examination is made with the aid of a magnifying glass.

(3) Cut edges of rolled plate are frequently examined for laminations.

b. The Magnaflux method of inspection is regarded as an extension of the visual method. Where it can be used, it is more sensitive than the visual method for the detection of checks, cracks, and similar surface discontinuities. It is one type of magnetic testing applicable only to ferromagnetic materials and is of particular value because of its simplicity and great sensitiveness. It cannot be relied upon to reveal subsurface defects. The method* consists essentially in magnetizing the piece to be examined, sprinkling or otherwise covering it with powdered iron or magnetic iron oxide and examining the pattern formed by the adhering powder. A pattern is formed because particles of the magnetic powder tend to collect and to be held at points of magnetic leakage. The leakage is caused by discontinuities in or very near the surface of the metal. Those most effective in pattern formation are cracks or other defects of narrow width and relatively great length. The "lines" assumed by the powder are easily recognized. The method may be used to determine, (1) the presence of cracklike surface discontinuities, and (2) the presence of laminations in rolled plate. It is sometimes used also to determine whether or not

---

* The reader should consult published literature for a complete description of the method and for details of its various applications. See reference at end of section.

a crack has been completely removed by chipping. In this case, the powder is sprinkled in the groove made by the chipper; however, when the cut is relatively deep, the results are not reliable.

c. Acid testing for surface defects consists in applying acid directly to metal to determine the presence of surface defects. As acids attack the metal producing a rough etched surface, this method of testing should not be used on highly finished parts after the finishing operation. Acids should be handled with care and, if possible, the treatment should be done outdoors or in a well-ventilated room.

Procedure

(1) The zone to be investigated should have a reasonably smooth surface. Any oil or grease, grinding particles or dirt should be removed carefully and the area wiped with a gasoline-soaked cloth.

(2) Acid enclosure: a plastic modelling clay such as "Plastacene", "Modeline" or "Milo Plastic Modelling Material", is placed in a ring or dam around the defect and carefully sealed to the surface by pressing and rubbing both inner and outer surfaces of the ring to the metal. The dam height should be such that about one inch of acid will cover the highest point on the surface.

(3) Acid mixtures and times for reactions are given in the following table. The strengths and times offered are not exact and can be varied to suit the conditions.

Material	Acid Mixture	Approx. Time
Carbon and Alloy Steels	2 parts conc. Hydrochloric acid 1 part conc. Nitric acid 1 part water	1-2 hrs.
Carbon, Alloy, and Stainless Steels	2 parts conc. Hydrochloric acid 1 part conc. Sulphuric acid 1 part water	2-4 hrs.
Nonferrous Metals except Aluminum	2 parts conc. Nitric acid 1 part water	Varies with different materials.

(4) Acid Removal and Cleaning.

After the acid has been in contact with the metal for the required time, it is removed by draining or syphoning. Water is added to the zone several times to remove traces of acid and the whole zone is scrubbed with a stiff brush to remove any deposit that may have formed. Further washing and quick drying will make the area ready for inspection. The zone is studied carefully with a suitable magnifying glass (preferably one that magnifies 5 times) using artificial illumination if necessary. Defects, such as laps, cracks, cold shuts, surface inclusions, coarse segregates, etc., are plainly seen as discontinuities or irregularities in the metal surface.

56. Proof Testing consists in subjecting structural parts or units to loads that produce stresses below the yield strength of the material but considerably above those expected in service. Hydrostatic tests of valves, pipe fittings, turbine cases, pressure vessels, and gymnastication of recoil mechanism, are examples. Welded bomb bodies may be tested by hydrostatic pressure. In this case, work

is placed in a cylindrical container slightly larger than the diameter of the bomb and sufficient pressure is applied to produce a small permanent deformation.

RADIOGRAPHIC TESTING (SUBSURFACE INSPECTION)

57. General

a. Radiography as an inspection tool is applied to the inspection of welds, weldments, and castings for the purpose of revealing evidence of internal soundness. It does not give evidence as to microstructure or physical properties. The application of the method to the inspection of welds and weldments is covered in the "Inspectors Manual for Arc Welded Structures."

b. For the purposes of acceptance, radiographic tests are carried out by, or for, the purchaser. Where the contractor has radiographic equipment, he may and usually does make negatives which are turned over to the purchaser. In such cases, the purchaser, through his inspector, exercises control over the radiographic procedure to the extent of assuring himself that the negatives are properly made and represent the material that he is purchasing.

c. Contractor's Responsibility. The contractor, where he makes the tests, is responsible for,

(1) proper preparation of the castings for test, including removal of risers and gates, cleaning, snagging, and in some cases rough machining in whole or in part.

(2) identifying areas radiographed and for proper identification of negatives.

(3) all operations involved in the production of the negatives, and for turning them over in good condition to the inspector.

(4) supplying to the inspector facilities for the examination of negatives and facilities for the comparison of the negatives with the castings themselves.

d. The Purchaser's Responsibility.

(1) It is generally recognized that the purchaser has an obligation to specify those parts or sections where complete freedom from macroscopic defects is required and to designate tolerable limits of soundness requirements for other parts.

(2) The purchaser, through his inspector, is responsible for determining whether or not the contractor has fulfilled his obligations. The qualification of procedure, complete identification of negatives, and various other specified details are involved. Some items that the inspector should consider may not be specifically stated, but may be implied in the contract. For instance, it is the responsibility of the contractor to deliver negatives in good condition that have been properly processed. Negatives that have adhering dust particles are not in good condition, and where fixing and washing is not thorough, they have not been properly processed. To avoid the dust, the darkroom should be kept clean and the films should be dried in a drying cabinet. Insufficiently washed negatives discolor with time and may become worthless for this reason.

(3) Finally, the inspector is responsible for the decision as to whether or not all pertinent details of the contract have been met and as to

whether the radiographic evidence indicates acceptable soundness conditions in the casting. In most cases, the evidence is definite and the decisions are easy. It sometimes happens, however, that there are uncertainties in interpretation so that there is a reasonable doubt. Such cases must be studied carefully. An example is found in the resemblance that sometimes exists between the images of tears or cracks with those of capillary pipes. One type of defect is re-jectable, the other usually is not. The inspector cannot shift the responsibility for the decision. If he is unable to satisfy himself as to the right interpretation, he should declare the image to represent the least acceptable condition.

58. <u>Procedure Qualification</u>. The contractor is sometimes required to demonstrate his ability to make acceptable negatives, because, if improperly made, the evidence they contain is impaired or lost. This demonstration is called the "Procedure Qualification Test" and consists essentially in making radiographic pictures of a test block furnished by the Government that are equal in quality to those taken of the same block which have been accepted as standard by the Contracting Officer.

a. The test block is illustrated in Figure 1. It consists essentially of a stack of carbon steel plates. The plate at the top contains cracks. A penetrameter (see paragraph 59) is placed on the top plate. For ordnance work, tests are made usually with the plates stacked to 1" and to 2".

b. No restrictions are placed upon the contractor in the making of the negatives He is required to produce a negative that shows image details of the cracked plate and the penetrameter with acceptable clarity The complete details of procedure, including the name of the responsible operator that produced acceptable negatives, are reported to the inspector. This accepted procedure is then followed in production work.

c. Procedure details to be reported include:

1 - type of X-ray equipment, tube rating and permissible value of d/t (see paragraph 58d).

2 - value of d/t.

3 - type of film.

4 - type of intensifying screen used.

5 - filter.

6 - tube current.

7 - tube potential.

8 - developer formula and temperature chart.

9 - condition of the developer (fresh, partly exhausted, etc.)

10 - temperature of developer.

11 - development time.

12 - fixing time.

13 - washing time.

d. d/t represents the ratio of the tube distance to the film distance, as shown in Figure 2.

It is important because X-rays do not proceed from a single point on the surface of the X-ray target but from an area. Due to this fact, the tube distance must be large relative to the film distance in order that sharply defined images result. The minimum value depends upon the area of the focal spot and this varies for different types of tubes. Where the minimum permissible value for d/t is not known, it should be determined experimentally. The method for doing this is illustrated in Figure 2. A picture of the cracked plate of the test block is taken with the tube distance 30" and with the film in close contact with the plate. This gives a sharply defined image. The film is then placed 2" away from the plate and a series of pictures is taken with the tube at various distances. The smallest tube distance that gives images as sharply defined as those obtained with the film in close contact is the proper tube distance for a 2" film distance. This tube distance divided by 2 is the required minimum value of d/t.

59. <u>The penetrameter</u> (see Figure 3) is a device used to test the correctness of the radiographic procedure in production work.* It consists of a strip of metal containing three drilled holes. The thickness of the strip is 2% and the diameters of the holes are 2%, 4%, and 6%, respectively, of the thickness of the metal to be tested, except that holes are made to nearest drill sizes and the minimum diameter is .03" (#69 drill). Different penetrameters are required for different thicknesses of metal. Up to 2", a new penetrameter is required for each 1/8" increment in metal thickness. In use, the details of the penetrameter images are used to judge the correctness of the radiographic procedure.

* A.S.M.E. Boiler Code Committee has adopted a similar penetrameter of 2% thickness but with 4%, 6%, and 8% diameter holes with a minimum of 1/16" diameter.

The characteristics of these images constitute the guarantee that the negative has been properly made It is of great importance that they be present in every production negative

60. Identification is one of the most important responsibilities of the inspector. The contractor places the identification marks but the inspector is required to check these carefully to make sure that they are complete and can be clearly identified Mistakes occur sometimes due to the use of symmetrical letters, figures, and markers. To avoid ambiguity, a bar should be placed under such numbers as 6, 9, 3, 8, and markers should be unsymmetrical in shape.

61. Reading of negatives and comparing them with official standards requires a special room. The photographic darkroom can be used for the purpose where such employment does not interfere with regular work. The normal eye is most sensitive to light that has the color values of ordinary daylight and that has an intensity just below the "glare" point. Manufacturers now supply films with a tinted base such that when used with a "daylight" diffusing screen, the light that reaches the eye has an approximation to the proper color values. The correct light intensity may be secured either by a dimmer in the light circuit or by holding the negative at a distance from the light source. The right intensity must be determined for each individual case This is not difficult, however, since with a little practice any reader more or less automatically adjusts the light to his eye.

62. Casting Defects.

a. The most common casting defects detected by radiography are:

(1) Gas cavities of various types.

(2) Pipes,
- concentrated
- diffuse
- capillary

(3) Slag inclusions.

(4) Sand inclusions.

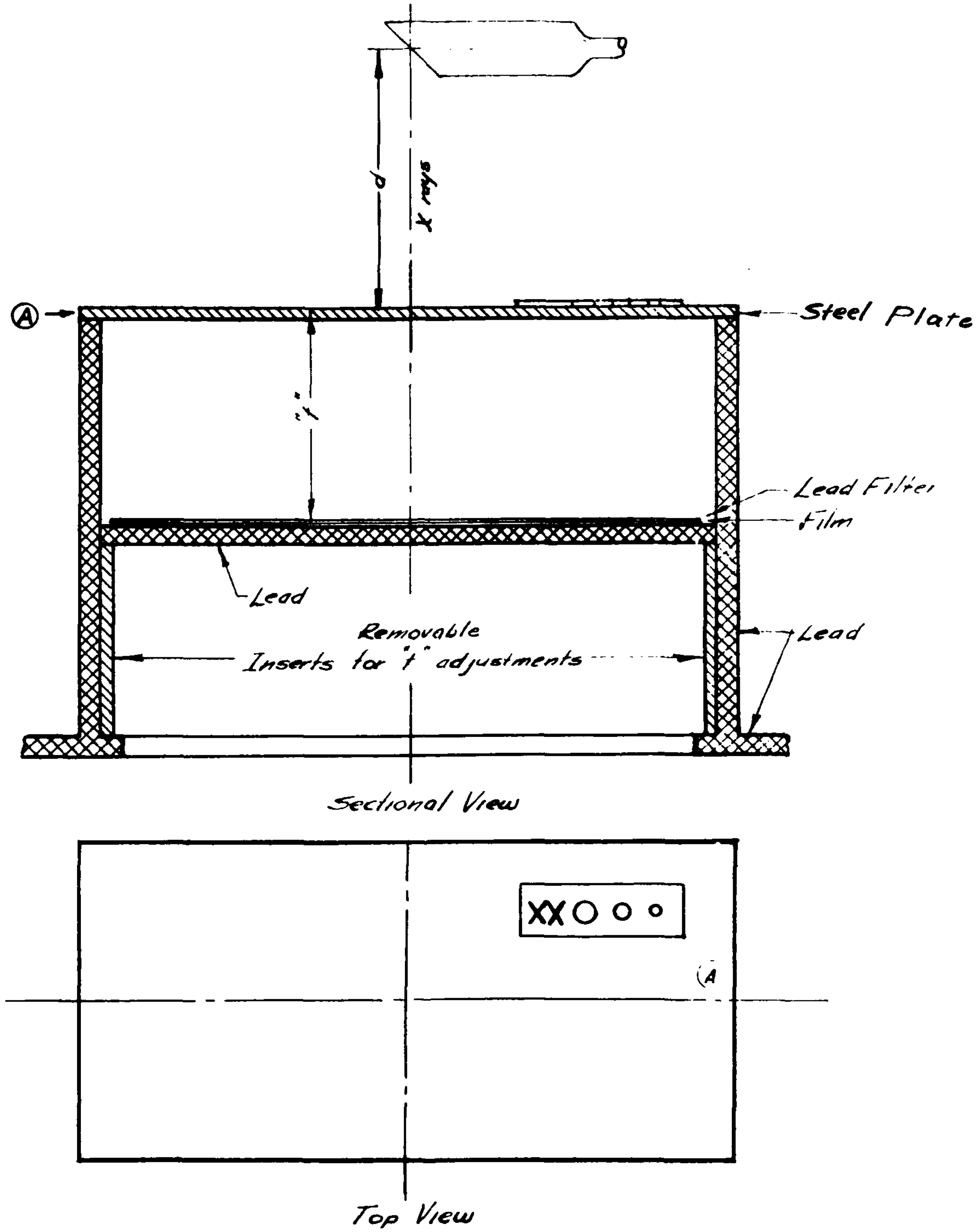
(5) Tears.

(6) Cracks.

Figures 4 to 12, inclusive, illustrate typical defects under the above categories. These illustrations are not to be regarded as standards.

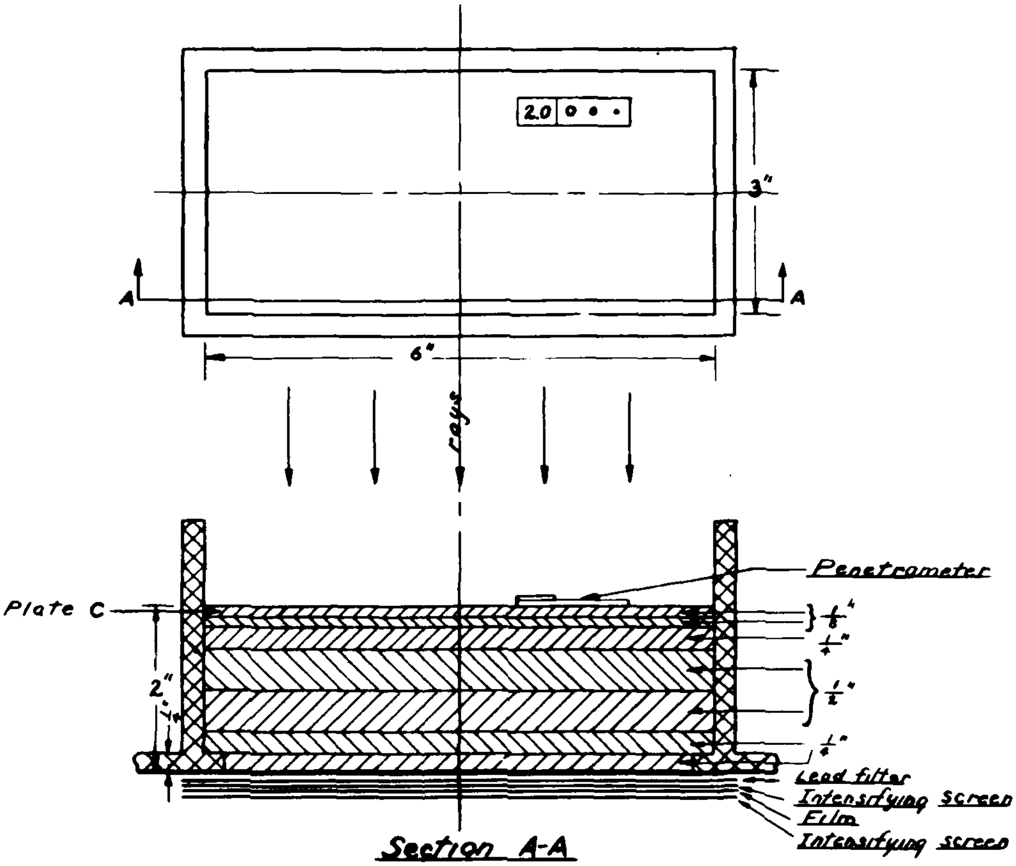
b. Rejectable Defects.

Cracks are usually rejectable although repair by welding may be permitted. Other defects may or may not be rejectable and may or may not be repairable. The decision as to acceptability is governed largely by the magnitude of the defects and by the type of service that the casting is to perform. Because of the variability of the factors involved, the decision as to acceptability is often difficult. In doubtful cases where the importance justifies it, the inspector should refer the matter to higher authority.



(A) Steel plate ¼" thick containing cracks

Fig. A



RADIOGRAPHIC TEST BLOCK

DIAGRAMATIC SKETCH

FIG. 4 W.A.639-3166

X - RAY

PENETRAMETERS

ARMY ORDNANCE

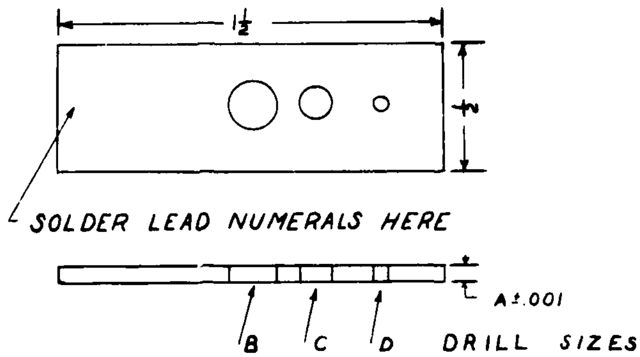


PLATE IN INCHES	PENETRA-METER NO.	DIMENSIONS (USE NEAREST DRILL SIZE)			
		A	B	C	D
¼	0.25	.005	(69) .03	(69) .03	(69) .03
⅜	0.38	.008	(69) .03	(69) .03	(69) .03
½	0.50	.010	(60) .04	(69) .03	(69) .03
⅝	0.63	.013	(56) .05	(60) .04	(69) .03
¾	0.75	.015	(53) .06	(56) .05	(69) .03
⅞	0.88	.018	(50) .07	(56) .05	(60) .04
1.	1.00	.020	(46) .08	(53) .06	(60) .04
1⅛	1.10	.023	(43) .09	(50) .07	(60) .04
1¼	1.30	.025	(39) .10	(46) .08	(56) .05
1⅜	1.40	.028	(35) .11	(46) .08	(53) .06
1½	1.50	.030	(31) .12	(43) .09	(53) .06
1⅝	1.60	.033	(30) .13	(39) .10	(53) .06
1¾	1.80	.035	(28) .14	(39) .10	(50) .07
1⅞	1.90	.038	(25) .15	(35) .11	(46) .08
2.	2.00	.040	(21) .16	(31) .12	(46) .08
2⅛	2.10	.043	(18) .17	(30) .13	(46) .08
2¼	2.30	.045	(16) .18	(28) .14	(43) .09
2⅜	2.40	.048	(11) .19	(28) .14	(39) .10
2½	2.50	.050	(7) .20	(25) .15	(39) .10
2⅝	2.60	.053	(4) .21	(20) .16	(39) .10
2¾	2.80	.055	(2) .22	(18) .17	(35) .11
2⅞	2.90	.058	(1) .23	(18) .17	(31) .12
3.	3.00	.060	(C) .24	(15) .18	(31) .12
3⅛	3.10	.063	(E) .25	(11) .19	(31) .12
3¼	3.30	.065	(G) .26	(7) .20	(30) .13
3⅜	3.40	.068	(I) .27	(7) .20	(28) .14
3½	3.50	.070	(K) .28	(4) .21	(28) .14
3⅝	3.60	.073	(L) .29	(2) .22	(28) .14
3¾	3.80	.075	(N) .30	(1) .23	(25) .15
3⅞	3.90	.078	(5/16) .31	(1) .23	(20) .16
4.	4.00	.080	(P) 32	(C) .24	(20) 16

NOTE: NUMBERS IN ( ) REPRESENT NEAREST DRILL SIZES TO DIAMETERS CALLED FOR IN DIMENSIONS B, C, AND D

FIGURE 1

W.A.639-3822

Figure 4a

Buckshot Blowholes

Frequently found near base of risers. Gas vents to outside instead of passing up through the riser.

Figure 4b

Blowholes

A bad distribution. Gas vents along a parting line of the mold.

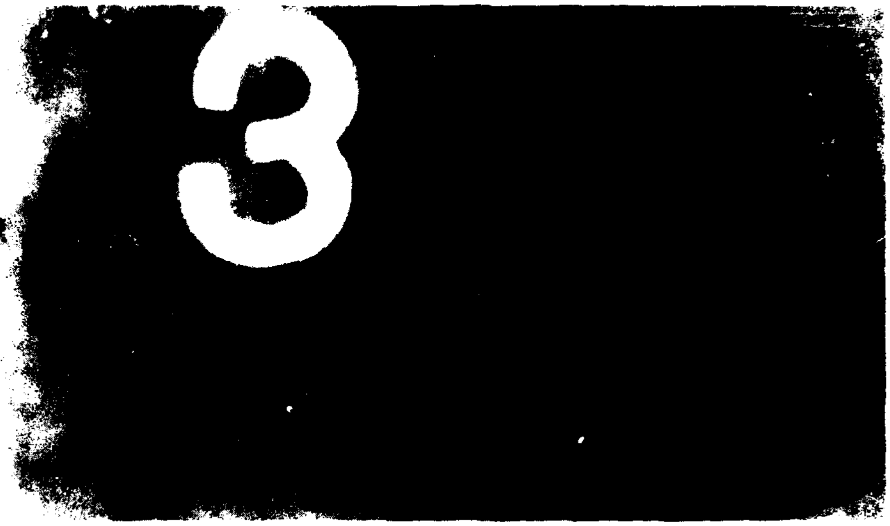

3

Figure 4c

Blowholes

Trapped gases within the metal tend to form cavities with rounded contours.

Figure 4d

Gas Cavities

Sometimes individual gas cavities are not large but they are numerous. This condition is illustrated in Figure 4d. In this case most of the cavities have tails. These may represent small channels through which the gas passed as it accumulated into the bubble. Similar tails are found when gas vents to the surface. Such gas conditions are often found near the bases of risers.

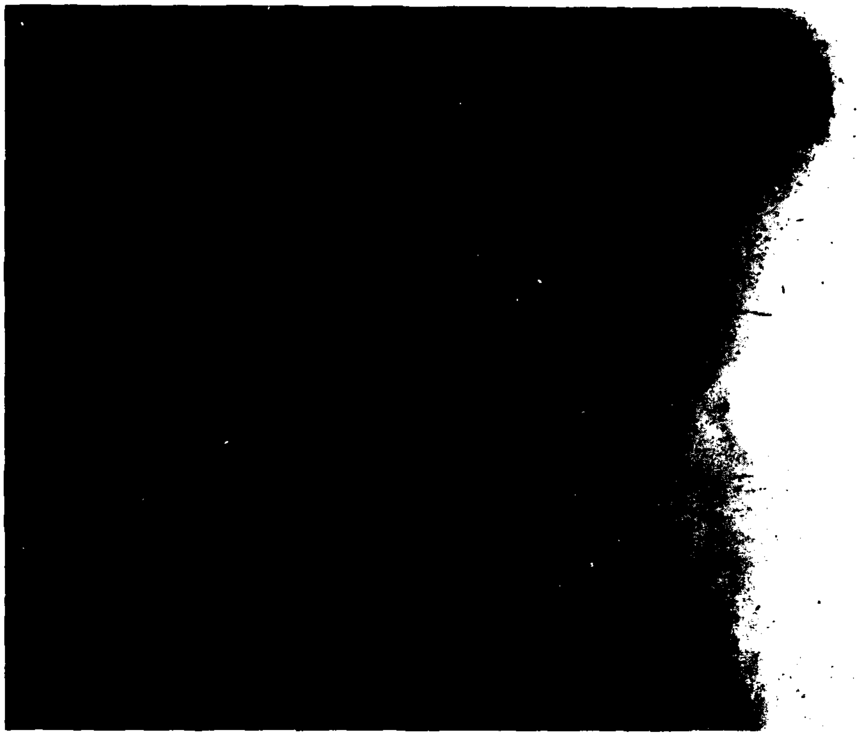


Figure 5a

Pipes, Concentrated

Metal in the molten condition occupies more volume than it does in the solid. Metal shrinks on freezing, hence there are apt to occur definite voids or porous regions in metal sections. Figure 5a illustrates a concentrated pipe system. Note that the metal adjacent to the cavity is fairly sound.


21

Figure 5b

Pipes, Concentrated

Concentrated pipe system which contains gas.
Part of the system is diffuse.

Defects in castings tend to be rather complex.

Figure 6a

Pipes, Diffuse

Piping may be represented by a few large cavities, as in Figure 5, or by a multiplicity of small ones. In Figure 6a the latter case is shown. The casting was cut to reveal this pipe, but there was no cavity evident to the unaided eye. The metal in the region of the pipe system was relatively soft.

Figure 6b

Pipes, Diffuse

Figure 6b represents a condition sometimes found in highly alloyed steels This condition is often referred to as "spongy metal" There are numerous small tears, and also some small gas cavities. The parallel marks are caused by brush marks in the mold wash


6

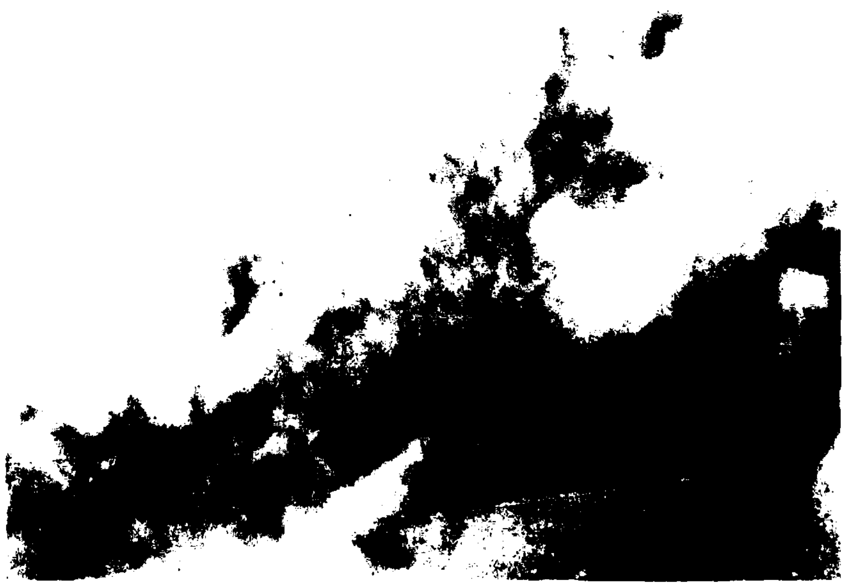


Figure 7a

Capillary Piping

In a relatively uniform metal section, such as the walls of cylindrical vessels or of cast plates during solidification, the molten metal is fed into the section from the riser and must pass through a constantly narrowing channel. Under these conditions, the central part of the section is incompletely fed and small cavities must result. Figure 7a illustrates the radiographic evidence of this condition

Figure 7b

Capillary Piping

Figure 7b is a radiograph of a section cut from the casting of Figure 7a and X-rayed through the cut surface Very often gas accumulates in the small pipes enlarging them

Figure 7c

Capillary Piping

Figure 7c illustrates a capillary piping that is often found in highly alloyed steel

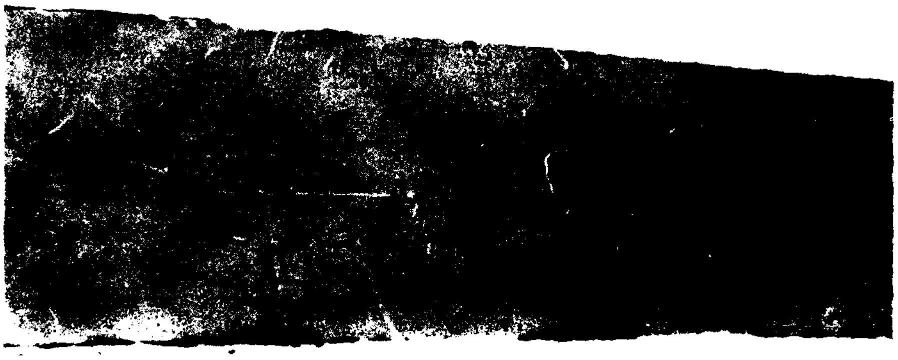


Figure 8a

Unfused Chill Rods

Chill rods sometimes do not fuse. When they have not been cleaned, the adhering rust or scale becomes sources of gas. The resulting condition is illustrated in Figure 8a. The escaping gas has actually formed a large blowhole above the chill rod.

Figure 8b

Unfused Chaplets

Dirty chaplets act in much the same way as dirty chill rods.

Figure 9

Slag Inclusions

The images of slag inclusions resemble those of gas cavities in that the contours tend to be rounded. In Figure 9 there is shown an unusual example of the slag inclusion which incidently, was not properly diagnosed until chipping had revealed its nature.

Figure 10a

Sand Inclusions

Sand inclusions are distinguished from gas cavities primarily by the fact that they are more angular in outline and the relative photo graphic density tends to be less than that of images of gas cavities. In Figure 10a the sand was trapped in the surface, probably due to the fact that dirt in the mold floats on the surface of the rising metal and occasionally gets caught on the wall of the mold

Figure 10b

Sand Inclusions Internal

Sand here occurs toward the center of the metal section rather than at the surface. Usually such distribution is a result of the cutting of the mold or gate by the incoming stream of hot metal. The X-ray picture itself does not distinguish between surface and interior sand inclusions Interior sand is found most often in the metal on the drag side of the casting

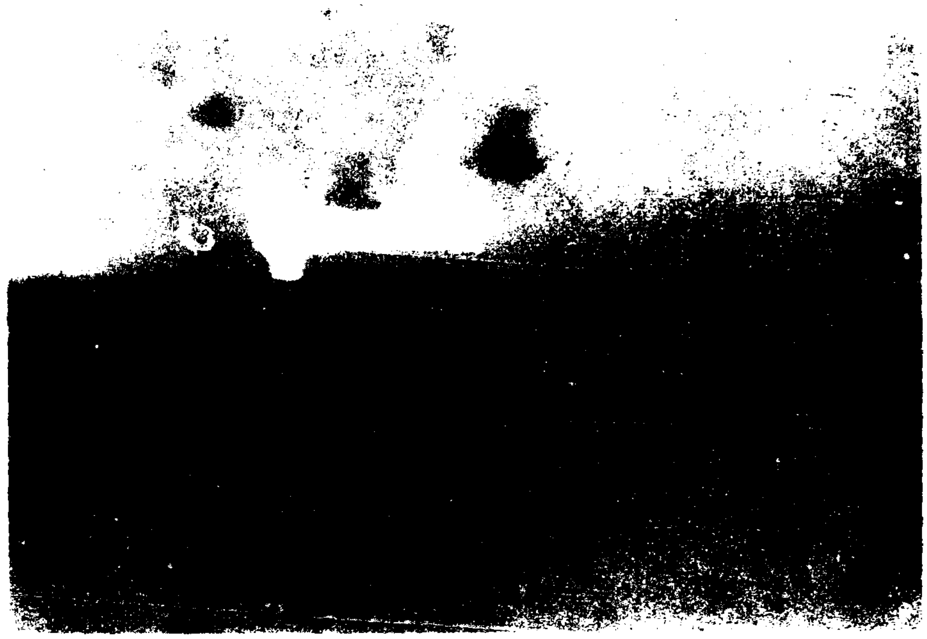


Figure 11a

Tears

Hot steel just solidified from the molten condition is quite "tender" It has little strength and is easily ruptured Ruptures occurring in this tender stage are called "tears" As the metal cools, it gains rapidly in strength and large forces are required to produce rupture. Ruptures produced when the metal is relatively cold are called "cracks" Tears may occur entirely within the metal and may not proceed to the surface. They tend to have parallel branches when there is a definite trend in one direction. In other cases they appear as localized ruptures with branches running in various directions. The tear is usually less sharply defined than the crack and the ends may be blunt Because of this and because they are often entirely subsurface, they are not such serious defects as are cracks.

Figure 11c

Tears

The conditions shown in 11b and 11c are more usual than that shown in 11a

Figure 11b

Tears

Figure 11b shows another tear equally as typical as 11a. Here the stresses were localized and more or less radially distributed about the region of the tear

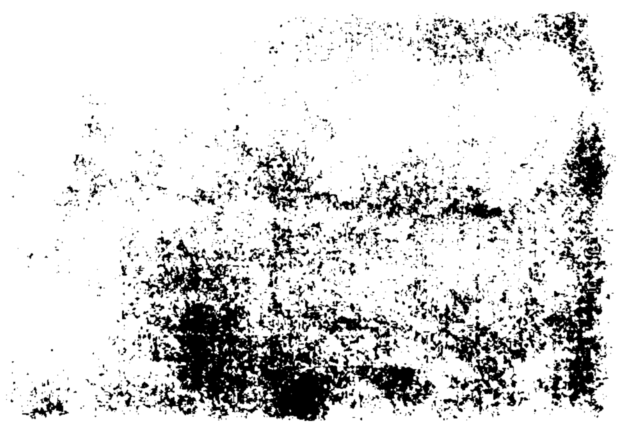


Figure 12a

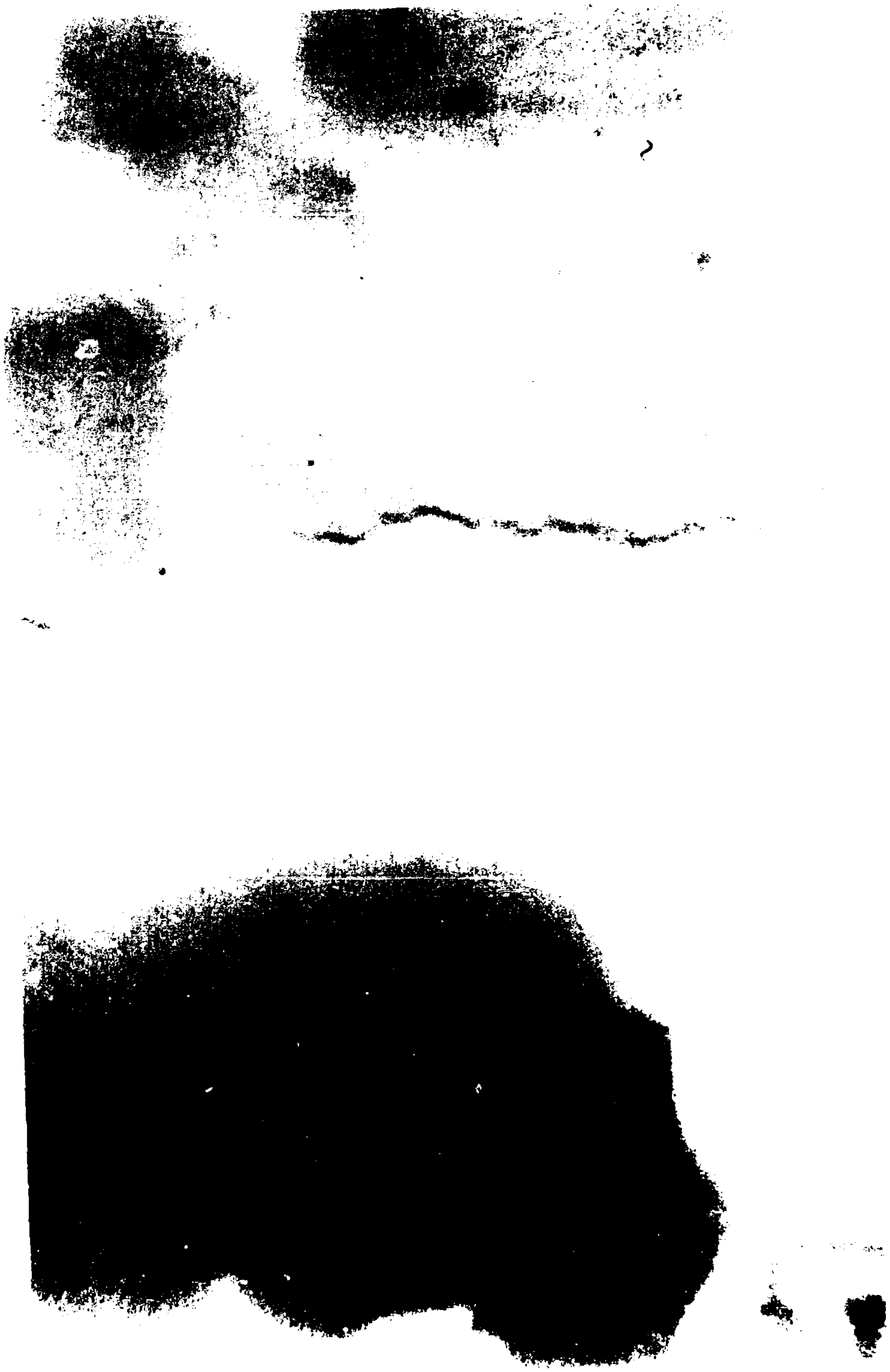
Cracks

Cracks tend to be single ruptures, but there are minor branches that tend to make acute angles with the direction of the principal rupture. They are distinctly secondary to the main rupture. In the tear the various branches may be of equal importance. The crack always carries to the surface, the tear may or may not.

Figure 12b

Cracks

There is no sharp distinction between tears and cracks, partly because the rupture may occur at any stage in the cooling down to room temperature. At room temperature there is a typical single line rupture. At temperatures just under the freezing point and somewhat lower there is the typical multiple rupture of the tear. This figure illustrates a borderline case.



BIBLIOGRAPHY

Magnaflux

1 - Yant, J. W., "Magnaflux Inspection of Pressure -Vessel Welds", Mechanical Engineering, 1937, Vol. 59, Mar., pp 145-6.

2 - Rathbone, T. C., "Detection of Fatigue Cracks by Magnaflux Methods", Mechanical Engineering, 1937, Vol. 59, pp. 147-152, March

3 - Cavanagh, R. F., "Magnaflux Inspection of Boiler Drums and Unfired Pressure Vessels", Mechanical Engineering, 1937, Vol. 59, Mar., pp. 153-155.

4 - DeForest, A. V., "Dynamic Strength of Machine Parts Affected by Quality of Surface", Iron Age, Vol. 135, Feb. 12, pp. 18-22

5 - The A. V. DeForest Associates, "Magnaflux - A Nondestructive Test Method of Value", a four-page pamphlet, published by the A. V. DeForest Associates, 898 Madison Ave., N. Y.

6 - Noble, H. J., "Magnaflux Inspection Methods in Airplane Engines", Metals & Alloys, July, 1936, pp. 167 170.

7 - Welding, Handbook, A.W.S., 1938.

8 - Manual for Visual Inspection of Welded Structures, Experimental Report No W A 640/36 (Ord. Dept.).

9 - "Nondestructive Tests in United States", A.S.T.M. Bulletin, Dec 1938

Radiography

10 - Symposium on Radiography and X Ray Diffraction, A.S.T.M., 1936.

11 Applied X-Rays - St John and Isenberger, J. Wiley & Sons, 1934.

12 - X Rays, Past and Present - Pullin and Wiltshire, Ernest Benn, Ltd., London

13 - Applied X-Rays (sec. ed.), G. L. Clark, McGraw-Hill Co.

14 Radium for Industrial Radiography - Gezelius and Briggs, The Chemical Radium Co., 1 E-42nd St., N. Y.

15 Engineering Radiography, Pullin, G. Bell & Sons, Ltd., London, 1934.

16 Welding Handbook, A.W.S., 1938.

17 - Fundamentals of Radiography (sec. ed.), Eastman Kodak Co., 1939.
The above is a commercial publication, but contains excellent descriptions of particular value to the practical radiologist - Eastman Kodak Co., Rochester, N. Y.

18 - X-Ray Protection - H.B. 20)National Bureau
Gamma Ray Protection- H.B. 23)of Standards
Everyone working with X-rays or gamma rays should have these pamphlets and should study them carefully.

19 Radium in Engineering Practice, V. E Pullin, Institution of Mechanical Engineers (London), March, 1933

20 - Discussion on Nondestructive Testing, Journal of the Inst. of Electrical Engineers (London), Vol. 84, No. 509, May 1939.

The above are books. A good bibliography of periodical literature may be found on page 699 and following of the 1938 edition of Welding Handbook issued by the American Welding Society.

SECTION VIII

MICROSCOPIC EXAMINATION

63 General. Microscopic examination is required only by certain specifications such as those for armor plate, tool steels, corrosion resisting steels and certain nonferrous materials It is for the purpose of determining grain size, grain boundary conditions, carbide distribution, and nonmetallic inclusions

64. Definitions of Metallographic Terms. See current edition of Metals Handbook (A.S.M.).

65. Sampling. Test metal may be taken from the section of the material, macro-etched discs, or from the butt ends of the physical test bars. In the case of castings and forgings, the locations of the test metal as well as the surface of the specimens to be examined are usually specified in the contract. If the metal is suspected of segregations, several specimens from different positions should be examined.

SPECIMENS SHOULD ALWAYS BE COMPLETELY AND CAREFULLY IDENTIFIED BY THE INSPECTOR.

When the contract does not specify otherwise, the following method of sampling is recommended:

(a) Cast Material - The section should be cut perpendicular to the surface so that variations of structure from outside to center can be observed.

(b) Forged or Rolled Material - The nature of the material determines the precise location of the test metal.(*) Both transverse and longitudinal sections should be examined.

(c) Gun Forgings - Radial sections are necessary for the proper study of the structure Specimens should be taken from both breech and muzzle ends

*Note: Macro-examination is a valuable guide for the proper selection of the location of the micro specimen

(d) Defective Material - The sample, if possible, should include the point of origin of the defect.

66. Cutting the Specimen. When the location of the specimen has been settled, the specimen may be cut by means of a hack saw, a band saw, a cutting-off wheel, or in the case of hard and brittle materials, it may be notched and fractured. Occasionally it is necessary to resort to flame cutting in order to obtain suitable specimens from large sections. Regardless of the means employed, it is essential to avoid heating and dragging the metal at the cut surface. With hardened steel, heating is particularly undesirable because it is likely to temper. To minimize heating during cutting, a hack saw should be used, with proper lubrication, for all specimens that can be cut by this means. Hard materials should be cut with cutting-off wheels operating under water. Dragging of the surface metal is a common defect encountered in specimens of soft materials. It can be minimized by lubrication of the saw blade. The structure of a flame cut surface is, obviously, not representative of the metal, and therefore not a suitable metallographic specimen.

67. Size and Shape of Specimen. Whenever possible, for convenience in subsequent handling, the size of the specimen should be within the limits of 3/8 to 1 inch square (or diameter) and somewhat less in thickness. Smaller specimens are not only difficult to handle but almost impossible to polish without rounding the edges excessively. Larger specimens are difficult to finish without scratches and without dislodging the nonmetallic inclusions. Specimens in which the height exceeds the linear

dimensions of the face to be polished are difficult to grind with the necessary flatness (1 & 2)

68 Polishing of Specimen. An accepted practice of polishing metallographic specimens consists of the following three steps (2)

(a) levelling on a surface grinder. This produces a flat face the preservation of which is aimed at during subsequent operations Grinding must be carried out with light cuts to prevent over heating and undue working of the surface.

(b) cutting the specimen on a series of dry papers of progressively finer grit sizes.

(c) wet polishing on a cloth covered disc, using one or more grades of abrasive

The resultant surface should be reasonably free from scratches and the nonmetallic inclusions should remain intact

69. Etchants. The more commonly used etchants to reveal the microstructures are listed in the current edition of the Metals Handbook (A.S.M.) (3)

70. Metallographic Examination. The inspector should consult references for methods of metallographic examination (3 & 4).

The standard procedure is to examine the unetched surface for nonmetallic inclusions. The Ordnance Department has not adopted inclusion count standards to govern the acceptance of material, although a few have been proposed by industry (5)

After examination in the unetched state the specimen is etched and examined at the magnifications specified in the contract or at such other magnifications as will reveal properly the structures to be investigated. In general, photomicrographs should conform to A.S.T.M. standards of magnification.[6]

Grain size standards used by the Ordnance Department are those established by the A.S.T.M.[6]

A few typical photomicrographs illustrating desirable and undesirable structure commonly found are given below.

References

(1) A.S.T.M. Standards, 1939, E3-39T.

(2) Watertown Arsenal Report No. 130/3, August, 1935.

(3) A.S.M. Metals Handbook, 1939.

Berglund, T., Metallographic Handbook of Etching, 1931.

Vilella, J. R., Metallographic Technique for Steel, 1938.

(4) Sauveur, A., Metallography and Heat Treatment of Iron and Steel, 1935.

Bullens, D. K., Steel and Its Heat Treatment, Vol. I and II, 1938 and 1939.

Williams, R. S., and Homerberg, V. O., Principles of Metallography, 1935.

Desch, C. H. Metallography, 1937.

Bureau of Standards Circular #113, Structures and Related Properties of Metals, 1921.

(5) Diergarten, H., Metal Progress, Sept. 1937, page 269.

Rinman, B., Kjerrman, H., and Kjerrman, B., Inclusion Chart, edited by Jernkontoret, 1936, Stockholm, Sweden.

Walker, G. W., Metal Progress, February 1939, page 169.

(6) A.S.T.M. Standards, 1936, E19-33 and E2-36.

PLATE I

Nonmetallic Inclusions

(a) Desirable - clean steel, with a uniform distribution of a small amount of nonmetallic inclusions.

Unetched X100

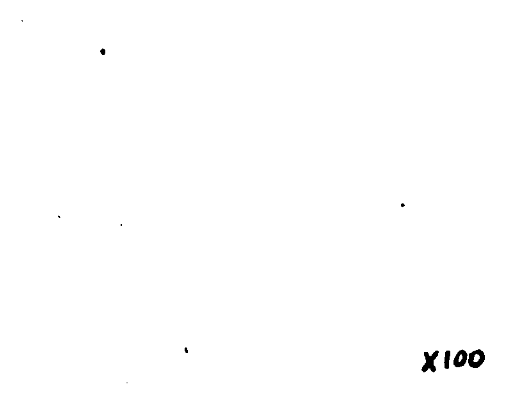
(b) Undesirable (Free Machining Steels Excluded) - dirty steel with long stringers of nonmetallic inclusions. Longitudinal section.

Unetched X100

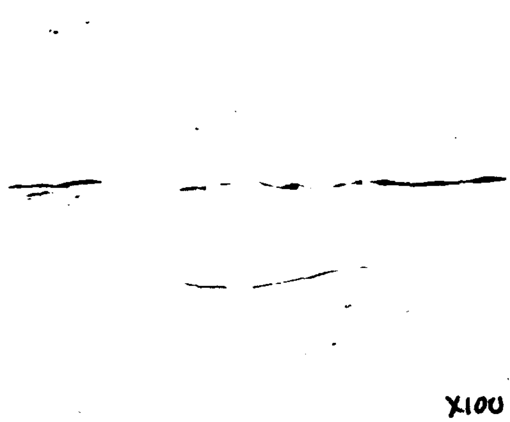
(c) Undesirable - dirty steel with streaks of closely associated nonmetallic inclusions. Longitudinal section.

Unetched X100

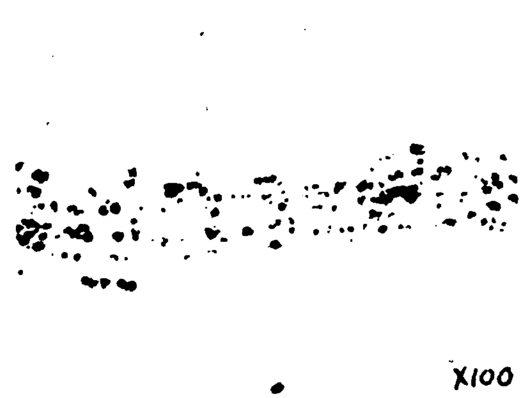
PLATE I.



a.



b.



c.

W.A. 639—1927

PLATE II

Various Types of Banded Structures

(a) Undesirable - severely banded annealed steel. Longitudinal section.

Nital Etch X100

(b) Undesirable (Especially if associated with nonmetallic inclusions) - severely banded heat treated steel. Longitudinal section.

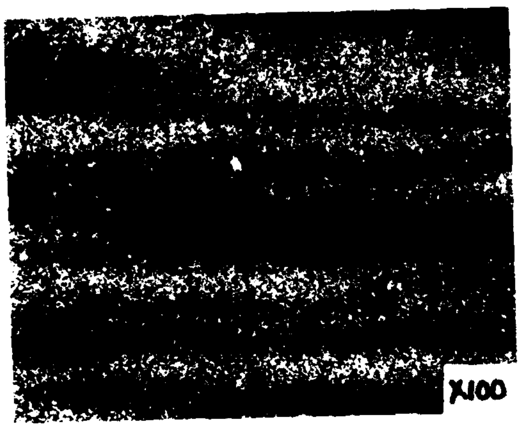
Nital Etch X100

(c) Undesirable - ferrite band containing long streaks of nonmetallic inclusion. Longitudinal section.

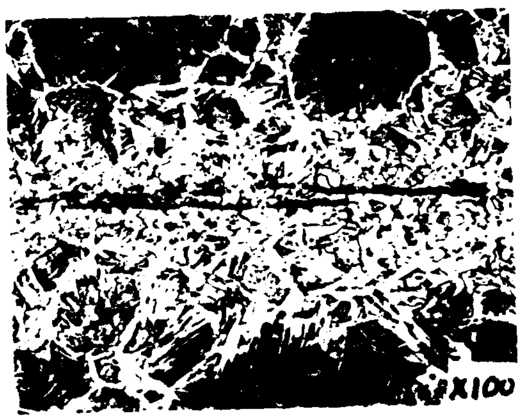
Nital Etch X100

PLATE II.

a.



b.



c.

W.A. 639—1928

PLATE III

Miscellaneous Forging Defects

(a) Undesirable - seam in the finished product.

Nital Etch X100

(b) Undesirable - crack associated with a non-metallic inclusion. Any type of internal crack may seriously impair the service of the material.

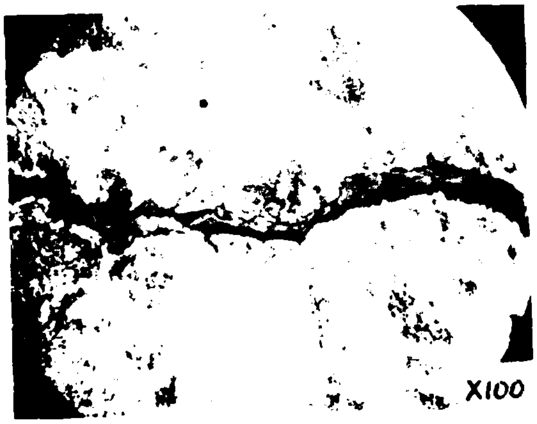
Nital Etch X100

(c) Undesirable - Remnant of pipe revealed in a longitudinal section.

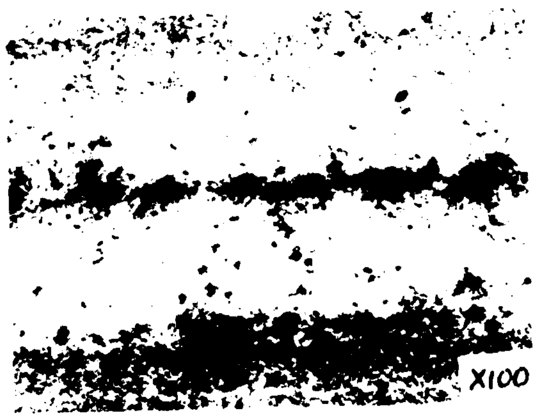
Nital Etch X100

PLATE III.

a.



b.



c.

W.A. 639—1929

PLATE IV A

Structures Resulting from Proper and Improper Thermal Treatment

(a) Desirable - fine grains in a forging - finished near the critical range.
Nital Etch X100

(b) Undesirable - coarse grains in a forging - finished at too high a temperature (can be rectified by heat treatment).
Nital Etch X100

(c) Desirable - fine grains of ferrite and pearlite in a properly annealed forging.
Nital Etch X100

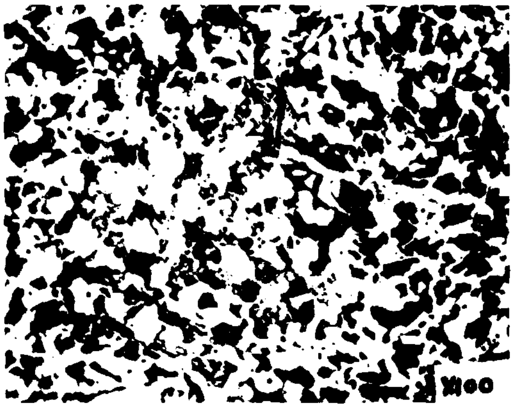
(d) Undesirable - Excessive grain size in an overheated forging - (can be rectified by heat treatment).
Nital Etch X100

(e) Undesirable - Oxidized grain boundaries and phosphorus segregations in burnt steel (cannot be rectified by heat treatment).

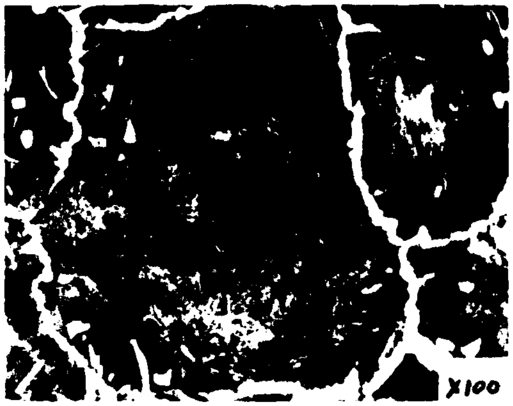
Etched in Stead's Reagent X50

(f) Undesirable - Decarburization - a soft ferritic skin on the surface of the finished product. Exterior surface at right.
Nital Etch X100

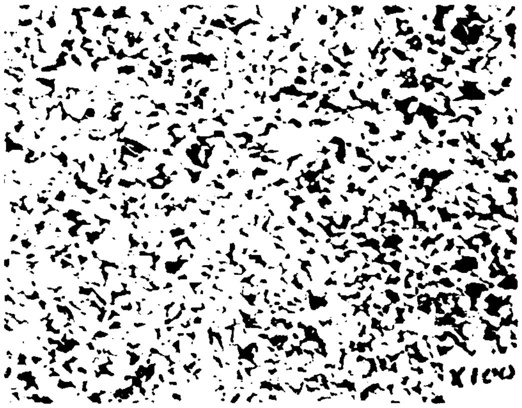
PLATE IV-A.



a.

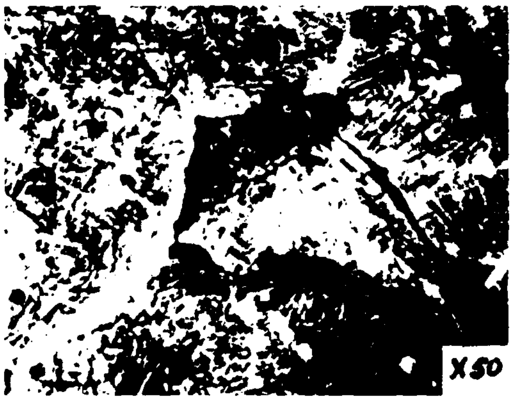


b.

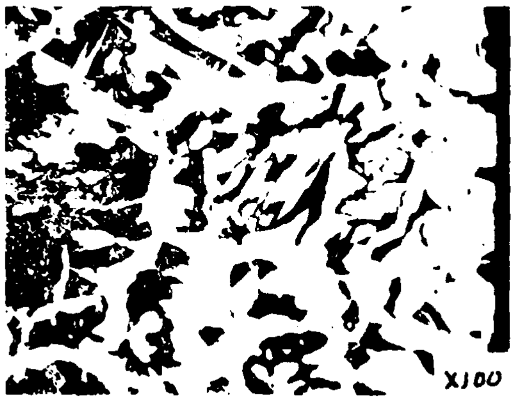


c.

d.



e.



f.

W.A. 639—1930

PLATE IV B

Structures Resulting from Proper and Improper Thermal Treatment - continued

(a) Undesirable - improperly heat treated steel with hard spots of martensite. (Can be rectified by heat treatment).
Nital Etch X500

(b) Undesirable - coarse grains of martensite in heat-treated steel. (Can be rectified by heat treatment).
Nital Etch X500

(c) Desirable - Properly heat-treated forging showing uniform distribution of carbide. This is an indication of complete grain refinement.
Nital Etch X500

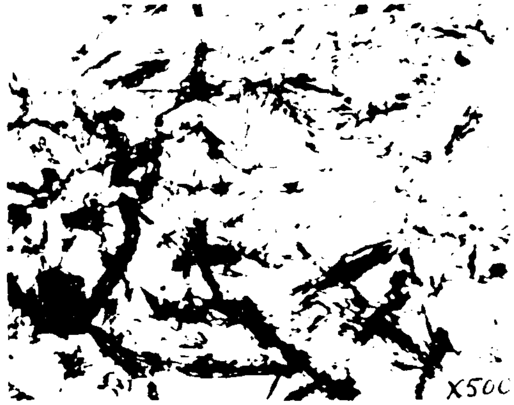
(d) Undesirable - improperly heat-treated forging showing coarse grain with non-uniform distribution of ferrite and carbide. (Can be rectified by heat treatment).
Nital Etch X500

(e) Desirable - Complete spheroidization of high carbon steel.
Nital Etch X1000

(f) Undesirable - partial spheroidization of high carbon steel. (Can be rectified by heat treatment).
Nital Etch X1000

PLATE IV-B.

a.



b.

c.

d.

e.

f.

PLATE V

Carbide Conditions

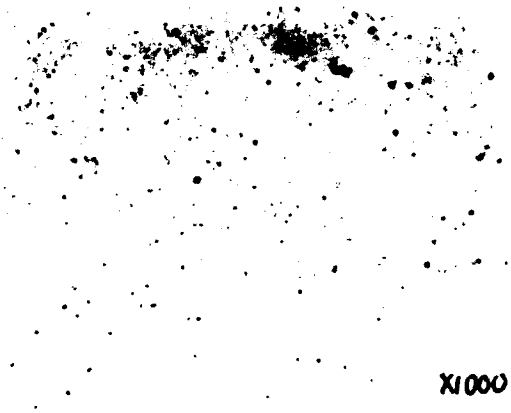
(a) Desirable - Uniform carbide distribution.
Murakami Etch X1000

(b) Undesirable - Carbide chains at grain boundaries.
Murakami Etch X1000

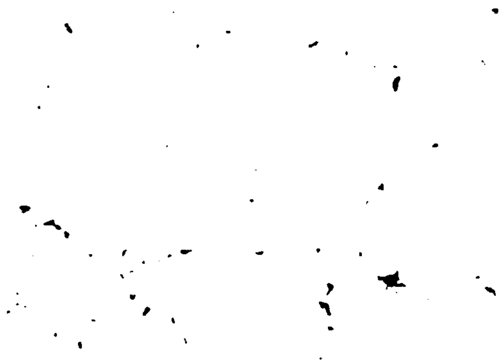
(c) Desirable carbide distribution in tool steel
Nital Etch X1000

(d) Undesirable carbide distribution in tool steels.
Nital Etch X1000

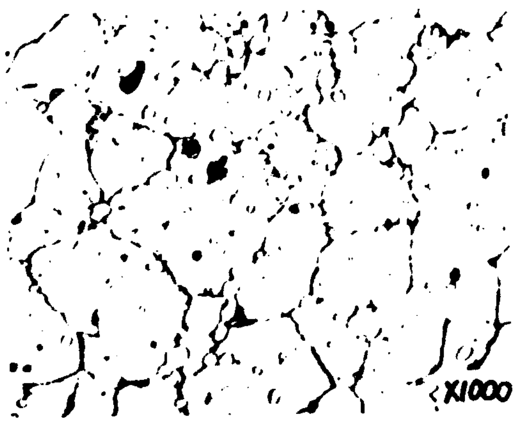
PLATE V.



a.



b.



c.

d.

PLATE VI

Structures of Carburized Cases

(a) Measurement of Depth of Case - Carburized case divided into three parts,

(1) Hypereutectoid zone, edge at left.
(2) Eutectoid zone.
(3) Hypoeutectoid zone, core at right.

The useful case depth is generally considered to be the sum of zones 1 and 2.
Nital Etch X100

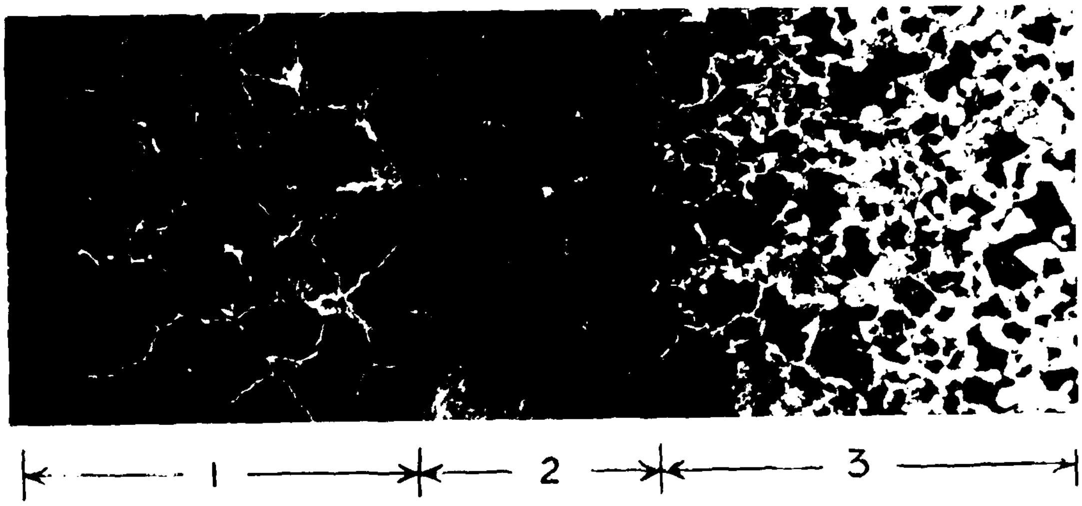
(b) Desirable - Normal Steel - A network of carbide surrounding the pearlitic grains in a hypereutectoid zone of a slowly cooled carburized steel.
Nital Etch X500

(c) Undesirable - Abnormal Steel - Islands of carbide embedded in free ferrite which surrounds pearlitic grains in the hypereutectoid zone of slowly cooled carburized steel.
Nital Etch X500

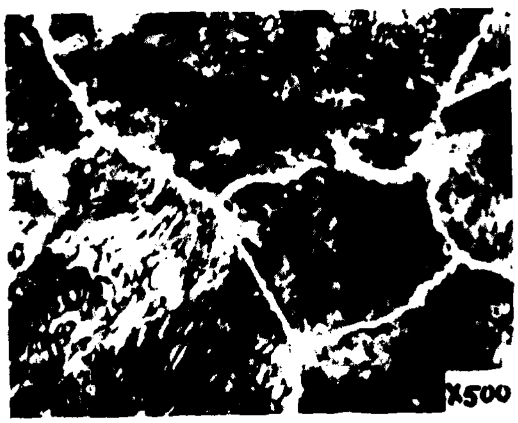
(d) Desirable - Normal Steel - Fine martensite found in the hypereutectoid zone of a hardened carburized case. Edge at left.
Nital Etch X100

(e) Undesirable - Abnormal Steel - Dark boundaries of troostite surrounding grains of martensite in the hypereutectoid hardened carburized case. Note: This condition produces soft spots. Edge at left.
Nital Etch X100

PLATE VI.



a.



b.

c.

d.

e.

W.A. 639—1935

PLATE VII

Copper and its Alloys

(a) Annealed Copper

Etched in Ammonia and Hydrogen Peroxide.
X100

(b) Undesirable - seam in brass.

Etched in Ammoniacal ammonium persulphate.
X100

(c) Desirable - small equi-axed grains in drawn or rolled annealed 70/30 Brass.

Etched in Ammonia and Hydrogen Peroxide.
X100

(d) Undesirable - coarse grains in drawn or rolled annealed 70/30 Brass.

Etched in Ammonia and Hydrogen Peroxide.
X100

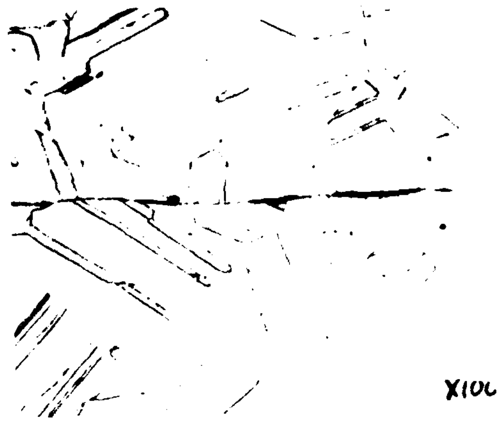
(e) Undesirable - "Season crack" in a Cartridge Case.
X3

(f) Undesirable - "Season cracks" in Cartridge Brass. Edge at right.

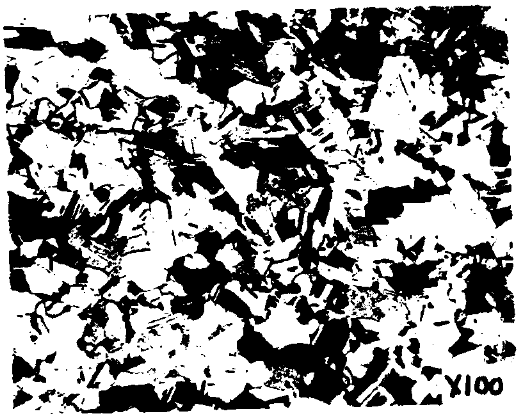
Etched in Ammoniacal ammonium persulphate.
X100

PLATE VII.

a.

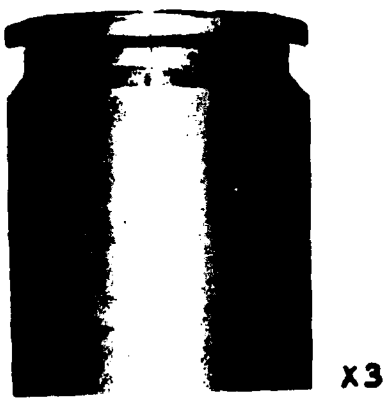


b.



c.

d.



e.

f.

W.A. 639—1933

PLATE VIII

Copper and its Alloys - Continued

(a) Desirable - Small uniform grains in 60/40 Brass. (Muntz Metal).

Etched in Ammoniacal Ammonium Persulphate X100

(b) Undesirable - Dendritic and coarse grains in 60/40 Brass. (Muntz Metal)

Etched in Ammonia and Hydrogen Perioxide X100

(c) Desirable - Uniform distribution of alpha and beta constituents in 60/40 Brass. Note: Beta is distinguished as a lemon yellow constituent with white light illumination.

Etched in Ammonia and Hydrogen Peroxide X100

(d) Undesirable - Segregations of beta constituent in 60/40 Brass. Identification of beta constituent--see note under(c).

Etched in Ammonia and Hydrogen Peroxide X100

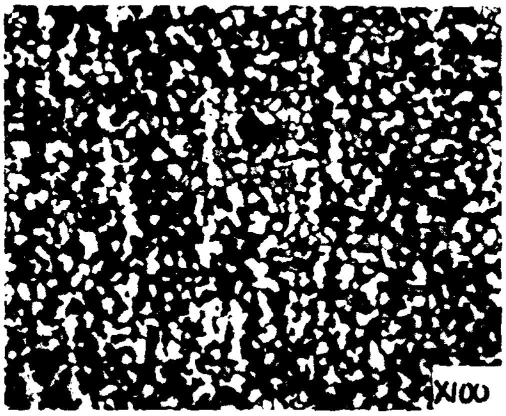
(e) Undesirable - Grain boundary cracks and porous area in cast bronze.

Unetched X250

(f) Aluminum Bronze, Aluminum 9%, Iron under 2%

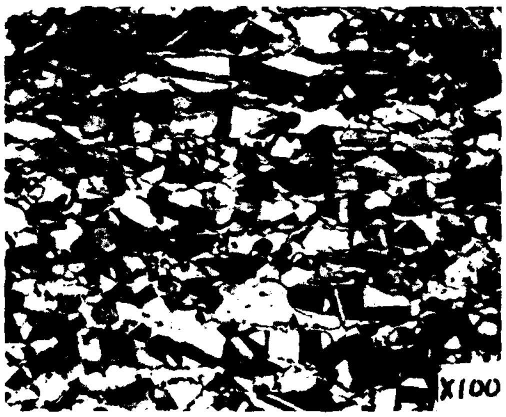
Etched in Ferric-chloride X100

PLATE VIII.



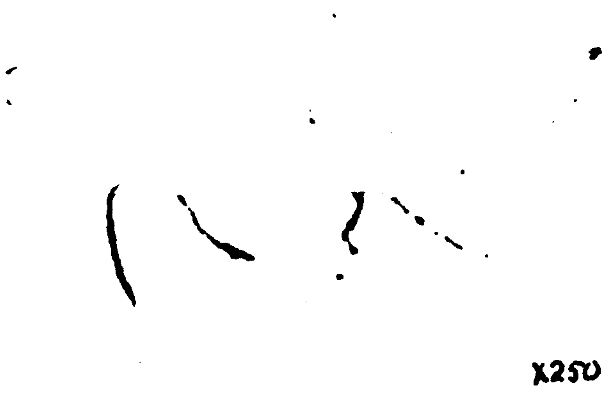
a.

b.



c.

d.



e.

f.

W.A. 639—193

SECTION IX

CORROSION TESTS

71. General. This section supplies certain details and explanations of those tests required in government specifications to determine the corrosion of materials in specific media, such as salt spray or copper sulphate solution, and the characteristics of metal coatings including anodized aluminum.

72. Materials Tested and Tests Used.* The following lists the materials tested and the corrosion tests that may be used to determine acceptability.

Material	Test
Protective coatings on Aluminum and aluminum Alloys	Salt Spray
Corrosion Resisting Alloy Steels	Salt Spray, Embrittlement Test, Sodium Cyanide Electrolytic Etch Test
Galvanized Products	Preece Test, Strip Test
Tin and Terne Plate	Strip Test
Zinc Electroplate and Cadmium Electroplate	Hull-Strausser Drop Test, Bend Test for plated specimens, Microscopic Test
Nickel, Nickel-copper and Chromium electroplated articles	Strip Test, Salt Spray Test, Microscope Test, Bend Test for plated specimens

* Some specifications provide for returning test articles for reprocessing. For detailed information regarding corrosion tests, see reference at end of section.

Material	Test
Zinc-Aluminum-Magnesium Alloy Die Castings	Humidity Test

73. Equipment required includes that usually available in the ordinary chemical laboratory and special equipment, such as salt spray apparatus and metallurgical microscopes.

74. Significant Surface for test purposes is that surface which is smooth, uniform and readily visible, and which has neither a decided prominence nor recess with respect to the general contour of the article and which is subject to corrosion or wear.

75. Preparation of Test Sample. Any grease film on a test surface will retard the action of test reagents and the subsequent error in results may be large. Test surfaces should therefore be cleaned prior to beginning the test. Cleansing is accomplished by use of vapor degreasers or by copious use of uncontaminated grease solvents, followed by light rubbing with a cloth moistened with a paste of a fine gentle abrasive such as magnesium oxide. The abrasive should be one that washes off easily. The cleanliness of the metal surface is determined by the "water-break" test. When dipped into clean water, a clean surface will be uniformly wetted, but if any grease film exists, the water film will break away from the dirty area leaving dry spots surrounded by wet areas of clean metal; in extreme cases the water will bead. Preparation of the test surface of corrosion resisting alloy steels should be carried out in strict accordance with specification requirements. Crocus cloth is made with iron oxide and should not be used.

76. Characteristics of Metallic Coatings on Metals. Coatings on metals are examined for one or more of the following characteristics.

a. Average weight per unit area* or average thickness. When the coating is stripped or chemically dissolved from the specified samples, the average weight per unit area is obtained. The average weight of coating per unit area may be converted to average thickness of coating by using factors supplied in specifications. In electroplating, special specimens are sometimes used, the thicknesses or diameters of which are accurately measured before and after plating.

b. Continuity. Porous areas and pinholes in coatings which leave the base metal exposed are detected by using the salt spray test. Electrodeposited coatings of zinc or cadmium, both of which are anodic to, and therefore, protective of, steel are not tested for continuity. Electrodeposited coatings of nickel, nickel copper and chromium which are cathodic to, and therefore accelerate the corrosion of, steel are checked for continuity.

c. Thin spots are places where the coating is of minimum thickness or minimum weight per unit of area and such spots are detected by using either localized or "spot" tests, as in the Drop Test, or stripping solutions that are slow in action, as in the Preece Test.

d. Adhesion of coating to base metal is determined by using special bend-test specimens or by scraping with the point of a sharp knife.

---

* Consideration should be given to the fact that the sheet may be coated on one or both sides.

e. Appearance is judged by visual inspection which reveals bare spots, rough spots, flux spots, blisters, lack of polish, staining, presence of serious abrasions and other defects.

f. Corrosion is usually determined in salt spray and the extent of corrosion is rated by the visual appearance. Aluminum alloys are sometimes subjected to tensile tests after exposure to salt spray.

77. Tests.

a. Salt Spray Test is conducted in a closed tank of neutral materials such as alberene stone. The spray should circulate freely and continuously about all specimens to the same degree No liquid that has come in contact with specimens should be able to drop onto other specimens or should be able to return to the aspirator to be resprayed. At the end of the test, the specimens are rinsed in water and are then examined visually. Deposits of corrosion products, characteristically colored according to the metals tested, usually reveal the extent of corrosion.

Coated ferrous materials, after salt spray test, are sometimes required to "show no sign of rust" or no "appreciable corrosion". The phrase "to show no sign of rust" is interpreted to mean the absence of red brown rust or rust spots when viewed at a distance of 12 to 18" without a magnifying glass. The term "appreciable corrosion" has been defined as the presence of more than six rust spots per square foot that are visible to the unaided eye, or of any rust spots larger than 1/16" in diameter.

Where plumb bob or beveled specimens of corrosion resisting alloy steels are used, they are examined on the cone or bevel and are rated in accordance with the following descriptions:

(1) "A" - ideal condition, practically perfect (note - a barely distinguishable trace of rust or stain is permitted under this classification).

(2) "B" - good condition, practically no progressive corrosion (note - definite staining due to rusting is permitted but no pits or etched areas should exist).

(3) "C" - fair condition, some attack but no excessive progressive corrosion, pitting or scaling (note - a greater amount of staining due to rust is permitted but no definite pits should exist, though a small area of etched metal may exist).

(4) "D" - poor condition, excessive progressive corrosion (note - bad staining and definite pits and large etched areas may exist).

The acceptable rating varies according to the grade of corrosion resisting steel tested.

b. <u>Preece Test</u> (Copper Sulphate Dip Test) is used for determining the presence of thin spots of galvanized coatings on steel. The number of dips or one-minute immersions (1/2 dips are 1/2-minute immersions) in the specified solution before the base metal is exposed* is taken as a measure of quality from the viewpoint of thickness of coating. The test is not suitable for determining relative

---

* Bright adherent copper is an indication that the base metal has been exposed.

weights per unit area of zinc coatings on steel.

c. Drop Test (Hull-Strausser Drop Test) is used for measuring the thickness of electroplated cadmium or zinc on steel. The specified solution is allowed to impinge, drop by drop, upon a definite spot on the article and the time for the first appearance of the base metal is noted. The composition and concentration of the solution are so adjusted that every second which elapses before the bright base metal appears is equivalent to 0.00001 in. thickness of coating. The drop test is usable for spot testing and suitable for measuring thickness rather than average thickness. The method is accurate within 15%. A variation of the Drop test is the Jet test in which the solution impinges continuously on the test area. This latter test is not described in specifications. Another variation that is permitted in specifications is to immerse the article completely in the test solution and to note the time for the first appearance of the base metal. This also serves to measure local thickness.

d. Strip Test is used to determine the average weight of coating per unit of area. The test specimen is measured and cleaned, and sometimes weighed, and is then placed in a solution that quickly dissolves the coating but has little or no effect on the base metal. The change in weight of the article, or the metallic content of the solution may be used to measure the average weight of the coating. The method is accurate to approximately 1%.

e. Sodium Cyanide Electrolytic Etch Test is used to reveal precipitated carbides in 18 Cr 8 Ni (Grade CRS #1) corrosion resisting alloy steel. When carbides are revealed, the embrittlement test is carried out (see paragraph 77 f). It is essential that no surface flow of metal occur during polishing and that no part of the electrical connectors dip into the electrolyte during etching

f. Embrittlement Test* is applied for detecting the susceptibility of 18 Cr 8 Ni type steel (Grade CRS 1) to intergranular corrosion. Bend test specimens are usually chosen and are boiled in the test solution for the specified period of time. After test, the specimens are bent through 180° and are examined for cracks (magnifications as high as X30 may be used).

g Humid Atmosphere Test (Steam Test) is used to determine the stability of zinc base die castings and their susceptibility to intergranular corrosion. Specimens are exposed for ten days over water maintained at 203°F (95°C). The changes in dimensions of the specimens due to this test are determined

h Microscope Tests The thickness of coatings on metals may be accurately measured by cutting a cross section, polishing, etching and examining under a microscope. It is essential that the cross section be normal to the plane of the surface under observation, that the edge be adequately protected against rounding during polishing, and that polishing does not smear either the base metal or plate

i. Plant tests are provided in certain specifications to permit inspection during manufacture. Sheets to be galvanized are taken after pickling and are dried and weighed. After coating

---

* Known also as Decay Test, Weld Decay Test, Test for Stability of Structure, Test for Precipitated Carbides, Strauss Test, Boiling Acid Copper Sulfate Test.

in the regular manner, the sample sheets are again weighed in order to obtain the average weight of coating.

In electroplating, thickness of plate is controlled by current density* and time of plating.

j Special Test. The Brenner Magne-Gage is a mechanical, nondestructive, rapid test for measuring the thickness of certain coatings on metals. The accuracy is about 10%. The instrument is new and is not described in specifications but is used in industry.

* Current density is current in amperes per unit of area of article being plated. Usually, as current density is increased, time of plating can be proportionately decreased. Regulation of voltage is not a controlling factor except so far as it permits obtaining the desired current density.

BIBLIOGRAPHY

1. A.S.T.M. Standards, 1936.

2. A.S.T.M. Tentative Specifications, 1936.

3. Protective Value of Nickel and Chromium Plating on Steel, Wm. Blum, P.W.C. Strausser, A. Brenner, Jnl. Res. Nat. B. of S., 13, 1934, 331.

4. Accelerated Tests of Nickel and Chromium Plating on Steel, P.W.C. Strausser, A. Brenner, and Wm. Blum, Jnl. Res. Nat. B. of S., 13, 1934, 519.

5. Corrosion Protective Value of Electrodeposited Zinc and Cadmium Coatings on Steel, Wm Blum, P.W.C. Strausser, and A. Brenner, Jnl. Res. Nat. B. of S., 16, 1936, 185.

6. Dropping Tests for Determining the Local Thickness of Electrodeposited Zinc and Cadmium Coatings, R.O. Hull and P.W.C. Strausser. The Monthly Review, 22, March, 1935, #3, 9.

7. Preece Test for Zinc Coating, H.H. Walkup and E.C. Groesbeck, Jnl. Res. Nat. B. of S., 12, 1934, 785.

8. Prevention of Intergranular Corrosion in Corrosion-Resistant Chromium Nickel Steels. P. Payson, A.I.M.E., 100, 1932, 306.

9. Corrosion Resistance of Iron Chromium Alloys in Various Media. The Salt Spray Tests. W.B Arness and J.N Ostrofsky. A.S.M., 20, 1932, 429.

10. Oxalic Acid as an Electrolytic Etching Reagent for Stainless Steels. G.A. Ellinger. A.S.M., 24, 1936, 26.

11. Metallographic Examination of Sheet and Strip. A.C. Sanford, Metals and Alloys, 9, 1938, 182.

12. Magnetic Method for Measuring the Thickness of Nonmagnetic Coatings on Iron and Steel. A. Brenner, Jnl. Res. Nat. B. of S. 20, 1938, 357.

13. Corrosion, Causes and Prevention, F.N. Speller. McGraw-Hill Book Co., Inc., N.Y., 1935.

14. Metallic Corrosion Passivity and Protection. U.R. Evans, Ed. Arnold and Co., London, 1937.

SUBJECT INDEX

(References are to paragraph and sub-paragraph designations)